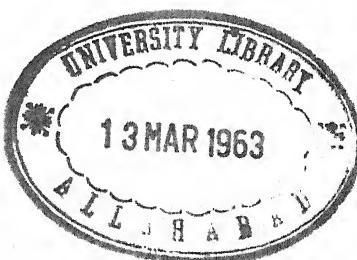

THE CHEMISTRY AND TECHNOLOGY OF FOOD AND FOOD PRODUCTS

Prepared by a Group of Specialists
under the Editorship of

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VOLUME II



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PREFACE

The extensive expansion of almost every field in the theoretical and applied sciences has made it very difficult for a single individual to survey any given field adequately. This is indeed true of food chemistry and food technology.

In presenting these volumes, 41 collaborators have tried to prepare a unified, authoritative work by approaching the problem from the point of view that an expert in any selected subject is best qualified to write about that subject. Thus, to cover the various phases of this work, food technologists, chemists, biochemists, bacteriologists, sanitary engineers, public health officers, food inspectors, and entomologists are represented among the contributors. It is our sincere hope that this book will fulfil a need in the literature of this field.

The two volumes are divided into a total of six parts. The first, on fundamentals, deals with the aspects of food chemistry which are common to all foods. The second part concerns the descriptive aspects of particular food groups and includes some account of the history, statistics, definitions, standards, composition, and chemistry of these food groups. In part three, unit operations and processes applicable to most foods are described. Part four deals with the maintenance of sanitary and quality control of foods and food products. In part five, the principal methods of preserving foods are delineated. Part six is concerned with production methods for the principal foods. Throughout the entire book, the role played by adequate nutrition in modern life is stressed.

There is, in certain respects, an overlapping of the subject matter in section two on descriptive aspects and section six on production methods. As a rule, a food group is treated in two separate but closely integrated chapters, each appearing in one of these sections. Where the material concerning a food group did not lend itself to treatment in separate chapters, the resulting single chapter is placed in part two, if more descriptive, and in part six, if more concerned with production.

In a collaborative effort, it is always difficult to avoid duplication. Such duplication has been permitted only when it is needed to maintain the continuity of a chapter or to simplify an explanation.

The collaborators and the editor wish to express their appreciation to those who have been of assistance in revising and correcting manuscript, reading and correcting proof, and preparing the index. We wish also to extend thanks for the permission to use copyrighted material and illustrations. This courtesy is acknowledged at appropriate points in the text.

Brooklyn, N. Y.
May 1944

MORRIS B. JACOBS

NOTE

The opinions expressed in this book are those of the individual authors. There is no presumption that these opinions are the official views of any branch of the Federal, State, or City Government.

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PART III

UNIT OPERATIONS AND PROCESSES



Chapter I

UNIT OPERATIONS AND PROCESSES (PART I)

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I. INTRODUCTION

Food may be considered as a fine chemical. It must be processed with care at least equal to that given industrial fine chemicals. In the latter case care must be taken to prevent contamination by small traces of elements and compounds from the processing equipment. For foods care must be taken not only to prevent accidental contamination of this type but also to preserve those trace materials vital to our health and well-being.

It is convenient to consider the processing to which food is subjected as a series of steps common to the processing of several foods rather than as an individual, characteristic method of an isolated food industry. If such a step is primarily physical in nature, such as weighing, measuring, conveying, disintegrating, grading, separating, mixing, coating, forming, etc., it is termed a *unit operation*. If the step involves a chemical change, such as fermentation, hydrolysis, coagulation, maturation, etc., it is termed a *unit process*. Such a classification is analogous to that used in chemical technology.

In food technology, however, such a rigid classification cannot be maintained, for not only are physical changes and chemical changes to be considered, but changes in palatability attributed to changes in odor, flavor, and texture are also of great moment. Thus, for instance, crystallization may be considered a unit operation when it is employed for the physical separation of crystalline sucrose from cane sugar sirup or beet sugar sirup, or dextrose from corn sirup, or of tartrates from wine; but crystallization may also be considered as a unit process in the manufacture of ice cream or candy, where the texture and palatability depend upon the fineness of the crystals formed. Other examples, particularly in the steps of heat treatment and emulsification, will be apparent in the discussion that follows. Some unit processes such as hydrolysis, coagulation, leavening, shortening, gelling, and extraction are common to so few food industries, that they are not treated in this section.

Foods do not lend themselves to processing according to the mass production idea; on the other hand, they can be processed in a semicontinuous line. It should be the first law of every processing plant handling fresh foods that these foods be

I. UNIT OPERATIONS AND PROCESSES

processed in the shortest possible time because, provided the processing procedures are satisfactory, the shortest lapse of time between the fresh and processed food results in the best product.

Too often processors are blamed for a poor quality product when the actual cause lies, not in the processing operation, but in production operations. A great many food products could be greatly improved in quality if rigorous control were to start at the point of production. Transportation from the point of production to the processing area should likewise be held under close scrutiny. It is obviously impossible for any food processor to convert a low-grade raw material into a high-grade product, regardless of the perfection of his process and processing equipment.

The producer and transporter cannot be blamed for all the low-quality foods on the shelves of our food retailers. The processor occasionally, but too often, uses equipment or processes which "will do" or "will get him by" rather than equipment that is designed to accomplish a certain task. We do not suggest that all old equipment be discarded and up-to-date equipment be installed, but we do feel that all replacements should be made by the most up-to-date equipment available.

Equipment manufacturers are subject to a certain amount of criticism. Much of the equipment used by the food processors should be streamlined and simplified, for the more simply the equipment is constructed the easier the operation may be carried out; simply constructed equipment is more easily cleaned, easily repaired and maintained, and usually batches are more easily duplicated. All equipment should be furnished with adequate control facilities, however. Corrosion, not only by the product but also by electrolytic effects from attached equipment, should be a prime concern of the equipment manufacturer. The technical service division is too often made up of salesmen rather than of trained food technologists.

The food chemist is, likewise, not without fault. A great many questions remain unanswered even for the most common food products. The plant chemist and botanist and others have studied the growing habits, and the effect of changes in these habits upon the composition, of most of our foodstuffs. They have also reported their studies on many varieties of the same kind of foodstuff. But far too many food chemists study a certain foodstuff without regard to variety, and it certainly cannot be assumed that all varieties behave identically under similar conditions. The food chemist must determine the effects of each processing step on each variety of every foodstuff. He must ascertain what changes take place during the processing and what effects are produced by altering processing conditions. The nutrition chemist must cooperate by determining which processed variety is the most nutritive, or where in the processing, the nutritious factor (or factors) was lost.

When all this information is compiled it will present an ideal picture:

- (a) The agronomist would tell us what to do to the soil to get the best results.
- (b) The botanist, horticulturist, and forester would tell us how best to grow the variety chosen.

- (c) The agricultural chemist would tell us what changes occur in the processing, and in the nutritional properties, of the product.
- (d) The food technologist would work out the best process for handling the product.
- (e) The equipment manufacturer would design and construct the equipment necessary to process the product according to the dictates of these specialists.
- (f) And the food processor would install and operate this equipment according to the plan laid down.

We must not let our imagination run away with us, however, for regardless of the high quality of the foodstuff and its high nutritive value the consumer will not accept a product lacking in flavor. After all, quality control, and in fact all food processing, must necessarily be governed by the flavor of the marketed product. The consuming public will eat anything it likes regardless of the price, but will not eat anything it does not like even though its food value is higher and its cost is lower. The problem can be easily summarized by the popular advertising slogan, "The taste's the thing."

In the following pages we have tried to point out some of the troubles the processor may encounter in his operations, and some possible reasons and cures, as well as some alternative procedures. For specific information, we refer the reader to those sections in this volume in which specific products are discussed.

II. RAW MATERIALS

1. Conveying

The types of conveying mechanisms used in the food industry are varied because the foods to be handled vary so greatly in their physical condition and in the method of their shipping. A few foods, food products or materials used in the food industries are shipped in bulk, but the majority of the conveying systems are those designed to transport barrels, boxes, crates, bags, drums, carboys, and the like.

(a) Solids

Hand Operations.—The wheelbarrow or handtruck is the simplest method of conveying food products from one place to another but is, of course, the least economical from the labor standpoint. About 2 cubic feet of material may be transported by one man in this way. Larger two-wheeled barrows having a capacity of 8 or 9 cubic feet are also sometimes used. In the larger food plants motorized trucks are used for conveying materials around the plant.

Belt Conveyors.—For horizontal conveying the belt conveyor is one of the most efficient forms of transportation. Cotton belts coated with rubber are especially designed for rough usage and cotton belts are better fitted for conveying boxes or packages. These belts are supported on rollers which are either flat or troughed. They are driven by a head pulley and the slack taken up by a foot pulley. The

capacity of the conveyor depends upon the width of the belt, its speed of travel and its shape, the troughed belt being able to carry two or three times as great a load as a flat one. Its large capacity combined with its small power requirement places the belt conveyor above other types.

Apron Conveyors.—Apron conveyors are made by attaching light strips of metal or wood to link chains. They are driven by a head cog intermeshing into the link chain. These strips form a continuous belt which is well adapted for handling light packages. Bucket conveyors are very similar in that small buckets, rather than the strips of metal or wood, are attached to the link chain.

Open-Link Conveyors.—Open-link conveyors are used generally, especially by the milling industry. They are capable of handling a greater capacity of a given material in a given time than any other form of conveyor, and at a low power cost. A thin, open-linked chain is placed at the bottom of a trough and covered to a considerable depth with any powdered or granular material. When the chain is set in motion it does not pass through the material but moves the material along with it in a solid body in a quiescent mass and at the same speed. Obviously this type of conveyor subjects the material to very gentle treatment. It is possible to feed the conveyor at any point or points and to discharge at any desired point or points, thus rendering the collection or distribution of products easily adaptable to special requirements. This type of conveyor is one of the cleanest, and is considered by some as the best available for the milling industry. The drag or flight conveyors are similar although not so efficient, because the material is moved by scrapers or bars attached to a chain, cable, or rope and pulled over the product to be moved.

Screw Conveyors.—Screw conveyors are useful only in transporting moderate quantities of material and are used mostly with finished materials. Many screw conveyors used are modifications of the simplest form, which consists of a series of metal flights bolted onto a shaft in such a way as to form an endless screw. The crescent design is one of the most popular, with each flight forming a half spiral because the conveyor can be made to deliver in either direction simply by reversing the flights to the opposite angle. The hollow spiral coil is the most popular for conveying grains. These conveyors are usually made of iron or steel although the trough may be of wood, brick, or metal.

Bucket Elevators.—Bucket elevators are a simple modification of the bucket conveyor. They consist of a series of buckets fastened between two chains, ropes, or belts (depending upon the nature of the driving mechanism) with the driving mechanism at the top end. The lower end is fitted with a means of taking up the "stretch." The bucket elevator picks up the material from a chute at the bottom and delivers it to a spout on the opposite side at the top. This form of elevator is used largely by the milling industry. However, since many materials are received at the food processing plant in packages, the bucket elevator is sometimes modified so that shelves replace the buckets. While the bucket elevator is continuous in operation, its modifications are usually intermittent to provide sufficient time for loading and unloading either manually or by automatic means.

Freight Elevators.—Freight elevators are especially useful in conjunction with hand or motor truck conveying in that a loaded truck may be elevated to the processing floor and unloaded at the processing point with minimum handling.

(b) *Liquids*

Gravity Flow.—Liquids are most easily transported by gravity through pipes or troughs. Water is usually conveyed through wrought-iron, plain, galvanized or cast-iron, lead, copper, tin, alloy, or plastic pipes; waste materials through earthenware or cement pipes; acidic liquids through glazed or vitrified tile, or glass or plastic pipes; beer and vinegar through wooden or glass pipes; distillery products through tin, tin-lined copper or iron pipes; and extracts through copper, brass or stainless-steel pipes.

Pumps.—Pumps are generally used for elevating liquids. These are driven by steam, electricity, water, belt, or gears, and the pumping obtained by the force of the piston in the plunger pump, or by the centrifugal force of the impeller fans in the centrifugal pump. The pulsometer and hydraulic ram are used to a very limited extent.

Acid Egg.—The acid egg is used generally for elevating corrosive liquids. It consists of a closed vessel constructed of acidproof cast iron or steel and lined with lead, ceramic ware, or plastic. The egg is heavily constructed so as to withstand high pressures. To operate it, the vessel is filled with liquid and the inlet closed, compressed air is admitted at the top, and the liquid is forced from the bottom through a tube or pipe to the point of delivery. The twin-cylinder type (also known as the Harris system) is a modified acid egg, the liquid being transported by alternate vacuum and pressure, the vacuum being used to fill the chamber, and the pressure, to move the liquid along.

Air Lifts.—Air lifts are also sometimes used, in which case a series of air pistons move the liquid along. In this group of conveyors, the contact of air with the product may be objectionable if vitamin retention is important.

Siphons.—A siphon is the simplest and most economical method of transporting a liquid but is limited in that it can only operate from a higher to a lower level. A very convenient form consists of a swivel pipe attached to the bottom of the tank and a chain for lowering it to the proper level.

Steam Siphons.—Liquids are sometimes elevated or transported by steam siphons. These operate by the difference between the velocity of a jet of steam issuing from an opening and that of a jet of water. Such liquids are heated by the steam and are also diluted by the condensing steam.

(c) *Gases*

Blowers.—Gases, whether valuable or not, must be conveyed around or removed from the plant. Pipes or flues of sheet iron, galvanized iron, cast iron, wrought iron, brick, concrete, lead, or wood may be used. Fan blowers consist of a number of

blades attached to a rapidly revolving shaft and are generally used to ventilate factory areas and to create drafts for the various heating mechanisms.

Chimneys.—Chimneys are often used to carry off noxious gases as well as to remove combustion products. Forced draft is sometimes used in conjunction with chimneys to increase their efficiency. If obnoxious gases are removed by a chimney it should be sufficiently high to prevent deleterious action on vegetable and animal life in the vicinity.

(d) *Pneumatic Conveyors*

In vacuum conveyors the material is moved by an air current and deposited in some form of receiver. This type is especially useful in unloading bulk shipments of powdery or liquid materials. Care must be taken not to use this method of conveying where the product is subject to oxidative changes.

(e) *Centrifugal Conveyors*

Certain dry, powdered substances may be pumped like a liquid by the addition of compressed air at appropriate places in the system. The material is fed from a hopper along with compressed air into a centrifugal pump. Obviously larger pipes must be used and an excessive number of direction changes avoided. The advantage of this type of conveying is that there is considerably less danger of dust explosion than is commonly associated with other conveyors.

(f) *Precautions in Conveying Food Products*

1. Fresh fruits and vegetables are susceptible to damage by bruising. Every care should be taken to avoid, as far as is possible, all unnecessary bumps and jars. If any container of these products is accidentally dropped, it should be segregated for very careful grading.

2. Many products, such as milk and fruit juices, are easily damaged by metallic contamination. Care should be taken that they come in contact only with non-oxidizing metals. Copper is probably the most undesirable metal because of its harmful action (through its catalytic oxidizing action) on flavor and vitamins.

3. Many products are damaged by simple contact with air. Products susceptible to air oxidation should not be conveyed by any of the systems using air.

4. Some products, such as flour and starch, are subject to dust explosion. Precautions must be taken to use those conveying systems which do not produce dust, or which are protected from an unlimited amount of air, or which are protected from sparks, hot bearings and flames.

5. All conveying systems should be so designed that no tendency occurs for the product to collect in inaccessible spaces where it may undergo decomposition and by its proximity to the sound material contaminate the entire pack. Vermin and

rodents are bound to be attracted to sources of such decomposing matter. See page 244.

6. All conveying systems in a food processing plant should be so designed that all parts are readily accessible for cleaning but yet protected as much as possible from vermin. See page 195.

7. Dusts, even though nonexplosive, should be avoided because of the possible contamination of the finished product by the unprocessed dust.

2. Weighing and Measuring

All materials entering and leaving the food processing plant should be weighed or measured. In fact, it is advisable periodically to weigh or measure the product at several points along the processing line, from which data and calculations the shrinkage or losses may be determined. Should unexpected losses occur at some particular step, a closer examination of this step should be made. In any event, the periodic weighing or measuring of the product along the line is of greater value than is usually recognized, for avoidable losses are lost profits.

3. Storage

One of the most important units in food processing is the storage (see page 314) of the raw materials so that undesirable changes cannot occur. Unfortunately, too many food processors store the raw materials in such a manner that they are temporarily "out of the way" without regard to quality changes. While considerable work has been done in determining the most favorable storage conditions, there is wide variation in the conditions specified in the literature. Since the literature is at variance on this subject, we can only illustrate typical storage conditions for certain products.

(a) Cereal Grains

Concrete Bins.—Cereal grains are usually stored in bins of three general types, *i. e.*, reinforced concrete, steel, or wood. In America the reinforced concrete bin is almost universally adopted for the storage of large quantities of bulk grain. It is economical to construct and to maintain; it is very strong and well adapted to resist lateral pressures of the bulk grain. It is also resistant to fire, vermin, and weather; and since the temperature changes are transmitted slowly they do not cause sweating.

Steel Bins.—Steel bins are rapidly erected and are relatively inexpensive. They are extensively used by farmers, by small manufacturers, and as a means of temporary storage by some large manufacturers. While they resist fire and vermin, unfortunately they readily transmit changes in temperature to the grain, often causing spoilage because of the sweating produced.

Wooden Bins.—Usually wooden bins require a brickwork shell with sufficient air space between the bin and the shell to permit expansion. Like concrete bins,

wooden bins are poor conductors of heat, hence no sweating occurs. However, they are subject to shrinkage, to warping, and are neither fireproof nor verminproof. They are used to a considerable extent for the storage of damp cereals.

(b) *Cereal Products*

Most cereal products are stored in containers adapted to an anticipated use. The containers may be cloth or paper bags, drums, kegs, and barrels. The changes which take place during this storage are very important. In the case of unbleached flour, storage results in a decrease in carotene content with a progressive improvement in apparent strength up to a fairly definite optimum. On further storage the strength gradually diminishes and the flour becomes more susceptible to overfermentation. These processes continue even in the absence of oxygen, from which it has been concluded that oxidation of flour pigments during aging has no connection with changes in gluten quality.

(c) *Fumigated Products*

Various products are sometimes fumigated to destroy the moths which attack them. On reaching the point of storage, cacao beans fumigated with hydrogen cyanide gas often contain as much as 50 to 80 parts per million of hydrogen cyanide. In these cases it is especially desirable to store such fumigated products in well-ventilated storage bins; otherwise the concentration of the gas from previous stocks may gradually accumulate to dangerous proportions.

(d) *Nonhomogeneous Liquids*

Various food products tend to separate out or "oil off" during preprocessing storage. Obviously this presents a problem from the angle of quality control.

Chocolate may be used to illustrate the problem of storage of such products because it is often affected. Chocolate is usually stored in a liquid form in the various departments in which it is to be used. A number of different types of water- or steam-jacketed vats suitable for chocolate storage are on the market. They differ only in agitator design which is, in this case, a most important feature. It is necessary not only to stir the chocolate continuously but also to keep it well mixed, for the cocoa butter tends to separate out. If this occurs, the previous processing operations are rendered ineffective. There is, however, a limit to the extent of agitation it is possible to use in the case of chocolate. Continuous beating of air into the mix must be avoided for it will lead to trouble in the subsequent processes. Furthermore, the agitators must be arranged to keep the chocolate continuously scraped from the sides of the vat or kettle to prevent overheating or overcooking.

As stated above this problem is not peculiar to the chocolate industry, but exists in some milder degree in the preparation of many foodstuffs.

(e) *Fruit Products*

The cold storage of fruit is rendered more complicated than that of meat or fish because the fruit is not passive but is a living organism evolving heat, consuming oxygen, and expiring carbon dioxide. The products of its respiration must not be allowed to exceed a certain concentration in the atmosphere of the storage room or the cells will die because of a diminished oxygen supply. The so-called "brown heart," a disease which has troubled Australian apple shippers, is considered to be attributed entirely to the suffocation of the fruit by the accumulation of carbon dioxide. Best results in the storage of fruits and vegetables are obtained when control of the composition of the atmosphere is maintained (see page 423). Some food plants arrange for absorption of the carbon dioxide from the air by caustic soda in a suitably designed scrubber. Under usual cold storage conditions a ton of apples will expire about 2.5 cubic feet of carbon dioxide per day, blackberries expire about 15 cubic feet, raspberries about 10 cubic feet, strawberries about 7.5 cubic feet, peaches and currants about 5 cubic feet. (See Vol. I, pp. 762 *et seq.*). In general, good air circulation and maintenance of a uniform temperature during storage are required.

Fruit storage rooms should also be rendered impervious to the absorption of the peculiar odor of the apple, which is most penetrating. Air circulated through an apple storage room should never be circulated over any other kind of produce because the apple odor will be picked up.

(f) *Vegetable Products*

Vegetable storage is considerably more simple than fruit storage because most vegetables after harvesting have entered a state of dormancy.

(g) *Eggs*

Egg storage presents problems not generally met with in the storage of other food products. Most authorities agree on the correct temperature of storage but there is a difference in opinion concerning the relative humidity which is most desirable.

In general, eggs should be stored at the lowest temperature possible without causing the solidification of the interior of the egg; otherwise the resulting expansion of the interior of the egg causes the eggshell to crack. This is a hard rule to apply because eggs with firm, thick albumen freeze at higher temperatures than do thin-bodied, watery eggs. The nature of the shell also affects the storage since thick-shelled eggs withstand freezing temperatures much better than thin-shelled eggs. Most authorities consider 29° F. as the ideal temperature, and ranges of 28° to 31° are used in practice. Regardless of the temperature chosen, the cold room should be maintained as uniformly as possible.

The problem of humidity is one that must be solved by each individual operator because variables such as climatic conditions, location of the storage rooms and the

TABLE 1

(See opposite page for references)

temperature chosen are limiting factors. Formerly these rooms were kept as dry as possible to prevent mold growth on the eggshell, but such a dry atmosphere also gradually withdraws moisture from the egg. This drying out increases the size of the air cell, destabilizes the egg contents, and accelerates the deterioration of the egg. Recent studies show that it is a better technique to maintain as high a humidity as possible and yet to prevent mold growth. Generally a relative humidity of 82 to 85% is most desirable.

Cracked eggs should never be stored with good eggs because they are likely to break in transit, the resulting leakage providing an excellent medium for mold growth which will, of course, extend to all the surrounding eggs. Probably more eggs spoil in storage as a result of cracked eggs packed with them than for any other reason.

Extremely long eggs which project above the dividers also should not be stored with other eggs because of the danger of cracking in transit.

Dirty eggs may be washed and stored with other eggs if they are properly dried after washing. Washed eggs deteriorate more rapidly than unwashed eggs when stored at summer temperatures. It is the general opinion of some authorities that, under the recommended storage conditions, properly washing and drying dirty eggs is preferable to leaving them unwashed. Until this question is solved scientifically it is advisable to observe caution in the washing process.

Eggs can pick up off-flavors not only from the dirt surrounding them but also from the materials out of which the packing cases are made. In general, manufacturers of packing cases have kept abreast of the times. More pulp fillers are now being used in place of strawboard since eggs can absorb odors from the strawboard.

Eggs should be placed in the cases with the small end down because the smaller end of the egg is stronger and thus more able to withstand shock than the large end. Furthermore, when the egg white weakens during storage, the yolk rises against the air cell membrane if eggs are packed this way; otherwise the egg yolk will adhere to the shell.

The storage problems confronting the food processor are still numerous, even though an enormous amount of work has been done in an effort to solve them. Through no fault of the investigators the problem is far from solved; and even though we may know the correct storage temperature, humidity, and gas control for a certain food product, the food processor could not afford to install separate refrigerating, air conditioning, and gas control systems for each individual food product. We must, therefore, determine and correlate all these factors for each individual food product,

* These values are weighted averages. The averages given in the table are not necessarily ideal storage temperatures, but do have a certain amount of significance in the relation of one average to another.

^b A temperature of 54° F. is generally used in transporting bananas from the West Indies, for lower temperatures result in chilling of the fruit and poor quality of the ripened fruit.

• Browning or pitting of the skin results at lower temperatures.

• Not critical to temperature but may cause dropping.

• Picked green and stored in a well-ventilated storage room until ripe.

^f Some users maintain that a temperature of 45° F. leads to a considerable improvement in the condition of the fruit when it reaches the market. This awaits scientific verification.

as well as for varietal, seasonal, regional, and other variations, and from such data enable the food processor to strike a happy medium in his storage conditions.

III. PROCESSING

1. Grading

Grading is the sorting of products according to size and quality. Of all the unit processes used in food technology, grading is one of the most important and may be the one in which the profits are made or lost. Too close grading causes the cost of the raw materials to go up, while too lax grading decreases the product quality. Obviously this is a problem for the individual producer to solve for his own particular product, but it is to be recommended strongly that close grading be utilized as much as possible.

(a) *Grading by Size*

Most fruits and some vegetables are graded according to size in steps of some multiple of a $\frac{1}{32}$ of an inch, which results in a standardization of processing techniques and thus greater uniformity in the finished product.

1. **Screen Graders.**—Most fruits and peas, string beans, beets, cucumbers, and asparagus are graded over vibrating screens containing numerous holes of sizes comparable to the product being graded. This type of grader usually has five or six interchangeable copper screens so that the same machine may be utilized for grading a number of products. Copper screens have been found suitable for the hard usage to which they are subjected; and while it has been claimed that they do not injure the color of the products, apparently little work has been done to evaluate them as a possible source of metallic contamination especially with respect to oxidative changes in the product.

In some models the larger holes are at the top thus segregating the larger product first and discharging it over the end of the grader onto a belt conveyor. The smaller product is then successively graded and handled in a similar manner. In other models the above procedure is reversed in that the smaller fruit is first removed; but the objection to this procedure is that delicately textured products are subjected to unnecessary movement which may produce soft spots and bruises.

Peas and similar products are usually graded by means of revolving cylindrical perforated screens with various sized holes corresponding to the different grades of peas. The smaller circular holes are located near the point of product entrance and the larger holes at the exit end.

2. **Roller Graders.**—This type of grader consists of two rollers, about 2 inches in diameter, which revolve away from each other. They are spaced closer together at the upper entrance end than at the lower exit end. The smaller product is removed at the upper end and the larger at the lower end. This kind of grader is highly recommended for spherical, unpeeled, or uncut products.

3. **Rope or Cable Graders.**—These consist of pairs of endless plain or rubber-covered ropes or steel cables traveling at an adjustable but diverging distance from each other.

4. **Slat Graders.**—Some products are graded in drums made up of slats of wood spaced according to the size of the product being graded.

(b) *Grading by Quality*

This step exerts considerable influence upon the quality of the finished product because a poor-quality raw material will not yield a high-quality product even though the processing equipment is the best obtainable and the process itself ideal. A product of higher quality can be produced from a high-quality raw material with poorly chosen processing equipment and process, than from a poor-quality raw material with the best processing equipment and process.

(a) Not all varieties are suitable for processing for the retail markets, so quality grading should begin with the choice of the variety to be used. Formerly most processors purchased the products on a price basis; but more and more processors are now including the variety name on the label—certainly a commendable practice because not all consumers prefer identical varieties. In such cases much consumer good will is obtained, for the practice enables him to buy just what is desired. No greater disappointment can be realized than a flavor of one variety of pack when another flavor is anticipated, even though both varieties may meet the standards of a fancy grade. Flavor differences attributed to variety are especially great in the case of tomatoes.

(b) The maturity of the product likewise exerts a very important influence upon the quality of the pack. As stated elsewhere in this chapter, overripe products interfere with processing, and underripe products lack the color, flavor, and aroma of the "firm ripe" ones. "Firm ripe" is a term used to describe the fruits which have attained full size and nearly full flavor, but which are not entirely ripe enough for table use. If ripe and underripe fruit are canned together, the former may be soft and mushy before the latter is sufficiently cooked.

(c) For highest quality, a product, unless properly stored, should be processed in the shortest possible time after harvesting. The quality of the product decreases rapidly with the length of time elapsing between harvesting and processing. This decrease in quality can, however, be suspended by proper storing. See page 314.

(d) The temperature to which the product is subjected between harvesting and processing must be considered, because objectionable deterioration is often catalyzed by higher temperatures. Fruit ripens more rapidly at higher temperatures and may even reach an overripe state prior to processing. See page 316.

(e) During peeling, scraping, trimming, and cutting of the product, the operators usually grade it by hand and reject the underdeveloped, damaged, and overripe fruit. From this point the product is again sorted on broad, slowly moving belts by operators trained for this work. With some products a third or fourth sorting is made—especially when the product is packed into containers. In up-to-date canning factories, the advantages of grading have long been recognized; and it is now generally conceded that the quality of the final product depends largely on the efficiency of the grading operation.

(c) *Waste Products*

In fruit canning only the fresh, sound fruit is utilized for processing. Thus there is almost always a certain quantity of good, edible, but waste, fruit which is picked

out as not being suitable for canning. This waste fruit may be utilized in any one of the following ways:

1. Crushed, packed, and sterilized for confectioners, etc.
2. Pulpel, concentrated, sweetened, and packed for ice cream, etc.
3. Pulpel and sold as such.
4. Pulpel and converted into jams, etc.
5. Pulpel and used in the preparation of flavors, fruit acids, etc.

2. Disintegration

WITHOUT APPRECIABLE CHANGE IN FORM

(a) *Husking*

Most of the larger processors use machines to husk sweet corn, although many processors still shuck the corn by hand. Many modifications of one basic design are used. Essentially all consist of a pair of rapidly revolving rubber or milled steel rolls against which the ear is held. The rolls catch the husks and remove them in much the same manner as wet clothes are carried through the rolls of a clothes wringer. The rolls should be kept properly adjusted at all times. If constructed of rubber they should be indented at the point of contact about $\frac{1}{8}$ to $\frac{1}{4}$ inch, and more tightly compressed at the discharge end than at the feed end because most of the husks pass through the rolls at the feed end. At the beginning of the canning season, the rubber rolls should be resurfaced prior to use in order to remove the thin, oxidized-hardened layer of rubber. At the conclusion of the canning season, the rubber rolls should be covered with paper. The rubber or steel rolls are usually kept wet during operation by means of a water spray, to prevent damage to the sweet corn.

The husking machine is equipped with a knife which cuts off the butts of the ears and also removes most of the silk with the husk. These knives should be sharpened frequently, that is, about twice daily, so that the cut will be smooth, the machine will operate smoothly, and the power consumption will not be excessive.

The butts of the ears drop into an apron spout at the back of the machine and then onto the husk conveyor. The husked corn passes through an apron spout onto a conveyor which takes it to the next processing area. The husked corn amounts to 70% of the original weight of the unhusked corn.

The husking machines, handling 60 to 80 ears per minute, are usually arranged in rows so that one pair of conveyors can serve the whole row. The machines must be supplied with sufficient power so that clean husking may be obtained and rolls are not choked when they grasp the first husks. Usually a long belt or a multiple V-belt drive is considered satisfactory because it is less likely to slip under load. All working parts must be well oiled. At the end of the season these machines must be coated with oil to check rusting and weathering.

(b) Silking

This step may be eliminated if the husking has been efficient. While most of the silk is removed by husking machines or by hand trimming, some processors utilize either one or both of the following silking methods:

One of the machines silks the corn in the ear by means of revolving brushes. While the ears are carried forward by rolls, the brushes remove nearly all the silk. The rolls discharge the ears into the washing machine where the rest of the silk is removed by water sprays.

The other machine removes the silk from cut corn by means of a wire screen cylinder, which acts as a sifter, and a series of wire fingers or gratings which intermesh as the corn passes through. These fingers catch and remove the silks, the screen permitting the corn to pass through, but removing the occasional husk or cob fragments.

(c) Peeling

Abrasion.—Abrading machines are sometimes used in peeling carrots, parsnips, sweet potatoes, turnips, and the like. The wastage in peeling by this method is high (about 36% in the case of potatoes), and considerable hand trimming is required.

The apparatus itself consists of an upright steel cylinder about 30 inches in diameter and about 16 inches deep. The sides and bottom are coated with coarse carborundum crystals which serve as the abrading surface. The bottom of the peeler consists of a dish which revolves rapidly as well as undergoing an undulatory movement. As the dish revolves, the vegetables are rubbed against the rough surfaces and the peels thereby grated from them. A heavy spray of water running into the peeler washes away the grated peelings, and thus facilitates the peeling. About 50 pounds of potatoes can be peeled in 45 seconds by this machine.

Steam.—Some processors halve and pit peaches and arrange them on trays which are then placed in a steam box for 2 to 3 minutes; the skins are loosened sufficiently to be easily slipped from the fruit by hand. Washed beets are steamed in a retort at 220° F. for 20 to 25 minutes, then chilled in water and trimmed and peeled by hand. Potatoes are washed and placed in crates which are put in a retort at 240° F. for 9 to 12 minutes; the skins are then removed by hand. Steam peeling is also used for tomatoes and beets, and sometimes under pressure for sweet potatoes.

Hot Water.—Short-time immersion of halved peaches in boiling water loosens the skin sufficiently for its removal by hand. Tomatoes are sometimes immersed in hot water for 15 to 60 seconds, and then immersed or sprayed with cold water to cool the fruit and loosen the skins. Hot water is preferable to steam, not only because of the uniform heating, but also because of the cleansing action of the water. The hot water treatment is continued long enough to soften the skin but not long enough to soften the pulp or flesh or to heat the tomato. Heated tomatoes are usually cooled by water sprays over a conveyor and the skins removed by hand. Tomato quality is greatly improved by peeling before dehydration. Boiling water is used also to soften the peels of citrus fruit prior to peeling.

Caustic.—Peeling in boiling dilute lye solution is less costly, more rapid, and less wasteful of fruit than other methods. The lye-peeling method originated in the production of hominy, when the corn was peeled with wood ash leachings; the corn was boiled in this dilute lye until the skins could be slipped from the kernels by the fingers; and the skins were then removed by washing the lye-treated corn in running water.

Hominy is generally prepared by boiling the corn in dilute sodium hydroxide solution, followed by removal of the skins in revolving cylinders and running water. The application of lye peeling to the preparation of fruits for canning is considerably more recent, the first patent being issued in 1901 for treating prunes with lye to facilitate drying. The treatment is not prolonged sufficiently to peel the fruit but merely to check the skins. The first patent for lye peeling of fruits was granted in 1902. It was pointed out that some sodium hydroxide was left on the fruit; but experiments show that the acidity of the fruit soon neutralizes the alkali.

For peaches, boiling in dilute lye solution causes the separation of the outer skin from the flesh beneath the epidermal layer, which is insoluble in the dilute alkali. The middle lamella of the cells consist of pectinous substances which are very soluble in the lye solution. The parenchyma cells of the peach are large and more resistant to lye than the cells immediately beneath the epidermis. The vascular bundles throughout the tissues of the fruit are also resistant to the lye solution. If the lye-peeling process is satisfactory, the pectinous substances of the middle lamella of the cells beneath the skin will be dissolved while the parenchyma cells will be uninjured. If, however, the peeling process is continued for too long a time or if the alkali solution is too concentrated, the surface of the lye-peeled peach will be rough and pitted by the action of the lye upon the fruit flesh.

In the case of sweet potatoes, the lye acts upon the cutin, for the cork cells comprising the epidermis are insoluble in the lye solution; because of this greater resistance the treatment must be continued for a longer time.

Sodium hydroxide is the most common form of alkali used in lye peeling, although a mixture of sodium hydroxide and sodium carbonate is sold as "canner's alkali." Sodium carbonate is less effective and more difficult to remove by washing. The most convenient forms of caustic for canner's use are the granular or flake forms which are approximately 95% pure sodium hydroxide.

Several forms of lye-peeling machines are in commercial use. The Dunkley lye peeler consists of a long, elevated, rectangular sheet metal box through which a wide, endless, woven-wire conveyor carries the food product. As it enters the peeler it is subjected to hot water sprays, the water being used repeatedly until the contaminants reach a concentration necessitating removal of the water. The washed and surface-warmed product is then passed under hot lye sprays which are applied below and above the screens, giving excellent contact between the fruit and the lye solution even though the product is not agitated during this contact. After the lye treatment the product is then subjected to a series of sprays of fresh cold water. The lye solution and the hot water are kept in tanks below the peeling chamber and circulated through the sprays by means of pumps. The Kyle peeling machine consists of a

revolving drum which carries the halved fruit through a tank of boiling dilute lye solution and then through a tank of running water. Some models have utilized water sprays in place of running water.

In most canneries, the lye-peeled fruit is passed through a tank of hot water at 140 to 180° F. to remove the last traces of alkali and to inactivate the oxidase enzyme at the fruit surface. This enzyme, which causes the browning of the flesh, is inactivated at about 180° in the case of the peach, whereas the lower temperature only removes the alkali. The browning of the fruit is inhibited by immersion for a few seconds in dilute hydrochloric acid, whereby the enzyme is inactivated by the hydrogen and chlorine ions present in the solution. The last traces of hydrochloric acid are removed by rinsing in water, although extensive rinsing is not necessary, since this acid forms harmless table salt with the residual alkali. A dilute (0.5%) solution of citric acid may be used but is not so effective.

An acid spray following the lye peeling is to be recommended because, for example, as in the case of peaches, the pH of the flesh is 3.8 to 4.0 although after lye peeling the surfaces are slightly alkaline. Darkening of the surface at higher pH values is extremely rapid because oxidase action is favored by a low acidity or slight alkalinity.

The concentration of the sodium hydroxide used varies greatly according to the variety and maturity of the fruit or vegetable. Usually 1.5 to 2.0% solutions are used; but more concentrated solutions are employed in the case of green products, and more dilute solutions for riper products or those which are more easily peeled. It is necessary to control carefully the concentration during peeling—if the concentration of the lye is too low, the peeling will be incomplete, and if too high, pitting of the fruit will result. Alkali concentration may be determined by titration, by conductivity, or by proportioners. This control not only effects a saving in the lye consumption but also prevents excessive loss in weight and undue decrease in the size of product during peeling. The alkali must, however, be replenished daily. The sodium hydroxide consumption amounts to 6 to 8 pounds of alkali per ton of fruit, but varies with the variety, maturity, and style of peeling machine used.

The temperature during the peeling operation is held near the boiling point. Heating of the fruit in hot water or steam before the lye treatment improves the peeling action.

The time of immersion depends upon the other factors, but is approximately inversely proportional to the concentration of the alkali. The output is affected by varying the time of immersion; usually an immersion of 0.5 to 1.5 minutes is employed and the concentration varied rather than adjusting immersion time.

Lye peeling is used for peeling peaches, apricots, and sometimes sweet potatoes and carrots. Lye peeling of pimentos is less satisfactory and is seldom used. Peaches are usually peeled in alkali of 1 to 2.5% concentration and sweet potatoes similarly, except that a stronger alkali solution is used and a longer treatment is required. Grapefruit segments are freed of pulp by treatment with 1% lye.

In the case of products which are difficult to peel, revolving brushes are used in addition to water sprays to facilitate the removal of the alkali-softened skins.

Roasting.—Pimentos, for instance, are roasted in a revolving steel cylinder which is heated by a direct gas flame. The cylinder makes about 12 revolutions per minute and the pimentos are heated for about 1 minute. Another method consists of carrying the pimentos through a firebrick furnace heated by an open gas flame. From either roaster the pimentos pass through a spray washer which removes most of the peel, and then over the peeling tables where the rest of the peel is removed. Roasting imparts a flavor not obtainable with other methods.

Oil Immersion.—Pimentos are passed through a bath of cottonseed oil at 400° F. for 3 to 4 minutes to soften the peels.

WITH CONSIDERABLE CHANGE IN FORM

(a) Peeling and Coring

Apples, pears, and similar fruits are peeled and cored by machine. Pineapple is peeled and cored by an apparatus known as the Ginaca machine; the fruit is fed onto an endless belt into the machine which trims off both ends, sizes the fruit, cores it, and removes the outer shell. Tomatoes are cored before pulping to reduce the worm content, since these work near the core; coring also greatly reduces the mold content of the product.

(b) Pulping

One of the essential machines in the manufacture of jam and similar products is the fruit pulping machine, which is an inclined circular sieve over which brushes revolve at about 600 revolutions per minute. The fruit is introduced onto the sieve from a hopper; the brushes disintegrate it; and the clear pulp passes through the sieve while the refuse is brushed from the top of the screen. These sieves, which are supplied in all mesh sizes down to 64-mesh, can be interchanged in a very few minutes.

In the earlier models, the brushes were attached directly to the brush shaft, and it was necessary to remove the whole shaft for replacement of the brushes. This disturbed the packing gland and sometimes caused considerable trouble because of oil running down the shaft into the pulp, while acid from the fruit sometimes got into the gearbox and corroded it. In the newer machines, the brushes and their holders may be removed in a few minutes and reversed, in order to even the wear on the brushes.

Older machines were extremely noisy, but many new designs have eliminated this trouble. Spiral gears running in an oil bath with ball bearings and thrust races permit the machine to be run at double the speed of the older models. The bottom end of the brush shaft rests in a hammock bearing so that it always runs true.

The pulped fruit may be delivered below the screen or at either side of the pulper as desired. This type of pulper is suitable for cooked citrus peel.

Tomatoes and similar products are pulped in a machine commonly known as a cyclone or pulper consisting of a heavy copper, monel, stainless steel, or bronze per-

forated sheet or screen in the form of a half cylinder which forms the lower half of the cylinder of the pulping machine. The upper half is of wood or heavy sheet copper. Heavy paddles revolve at a high rate of speed within the cylinder. The tomatoes are broken by impact of the paddles or by being thrown against the walls of the pulper. The pulp and juice pass through the screen into the tank, from which they are pumped to the processing area. The skin, seeds, and fiber pass out through an opening at the lower end of the pulper. The tomatoes enter the pulping cylinder through a hopper usually fed by a continuous conveyor.

Preheating fruit until it is thoroughly heated softens the fruit prior to pulping, and gives a higher yield of pulp which is richer in pectin and gums than are cold-pulped products. Preheating also destroys the microorganisms in the fruit and reduces the vitamin C loss by the inactivation or destruction of oxidative enzymes.

(c) Cutting

These machines, usually constructed of stainless steel or monel metal, were introduced to marmalade manufacturers for cutting citrus fruit peel into various thicknesses. Such machines can be easily handled for this purpose. By simply adjusting four screws, the orange portion alone of the peel can be cut into shreds or some of the white portion can be included.

Asparagus to be cut is first graded and then conveyed by belt to a table near a rapidly revolving circular knife. The operator holds the stalks against this knife in order to cut the asparagus to exact lengths. The loss in this operation usually amounts to 50 to 75%, but may be reduced by shredding the more tender butts for soup stock.

Corn was originally cut from the cob by hand, and an expert cutter was able to cut enough for 1000 cans per day. In 1882, Sprague invented the first mechanically operated cutter: the knives were held under tension by rubber rings which adjusted themselves to the ear size, although these rings required frequent repair and replacement. In later machines the rubber rings were replaced by springs, and the circular head by feed rolls having thin steel blades for forcing the ears into the cutter and thus giving a more uniform cutting. In modern machines, the ears are forced through circular knives whose position is varied by springs according to the size of the ear. Two sets of knives arranged in tandem may be used to double cut the corn, the first pair of knives to cut about one-half of each kernel from the cob and the second to cut the remaining portion. This improves the texture and appearance of the over-mature corn. The corn is fed into the cutting machine small end first since the knives adjust themselves to the ear more satisfactorily than if the butt end is fed first. The cutter knives must be sharpened frequently (every 5 to 6 hours) with special grinders; the machines should be arranged so that the working parts are readily accessible for repairs; and frequent oiling is necessary for smooth operation and for clean cutting. Scraping by blunt blades follows the cutter to scrape the remainder from the cob for Maine-style corn.

Okra is cut with a string bean cutter. Pumpkin is sometimes cut by special roller disks and the pieces washed in a revolving, circular screen, "squirrel cage" washer in order to remove seeds and fiber. Apricots are cut prior to drying; cutters average from 600 to 1200 pounds per day at a cost of from \$5 to \$7 per ton. Cutting peaches costs \$3.34 to \$3.46 per green ton.

(d) *Snipping*

Green beans are trimmed or snipped by hand in most canneries. Although attempts have been made to perfect an automatic snipping machine, they have not been too successful.

(e) *Pitting*

Cherries are pitted by an automatic machine in which the fruit falls into small cups and the seeds are removed by cross-shaped plungers. The loss amounts to about 15%, but is reduced by recovery of the juice for canning, jellies, or sirups.

(f) *Cutting and Pitting*

The simplest method, as well as the least economical, is cutting and pitting by hand. However, the grading factor must be considered. Operators who cut and pit stone fruit can also easily segregate from the firm ripe fruit the green, the overripe, and the pie grade material. Usually the fruit is delivered to and from the cutting tables by belt conveyors. A belt conveyor also handles the pits. But in the smaller canneries the operation is carried out on tables; since these are not equipped with endless belts the fresh fruit is delivered to the tables by hand and the refuse as well as the cut and pitted fruit is carried away.

In the hand operation a special knife is used to cut the fruit from the surface to the pit. If the fruit is not one of the freestone varieties, a spoon-shaped knife is then inserted from the stem end and the flesh cut from the pit. One cutter can handle about 72 pounds of finished peaches per hour.

Machine cutting and pitting are gradually displacing hand operations. Two styles of apparatus are available. Either the fruit is halved in one machine by means of a buzz-saw type of knife and conveyed by belt to another, hand-fed, machine where the pits are removed by an automatic crescent-shaped knife, or it is pressed between two knives and rotated, thus making a cut to the pit, then brought into contact with the crescent-shaped pitting blade and the machine started so that the gears move the pitting blade around the pit and drop the two halves from the machine for further processing. Should the pit split during this operation, the pitting is completed by hand.

(g) *Chipping*

This machine is constructed like a lawn mower, a number of blades being set spirally across a roller and revolving at a high speed against a stationary blade.

The blades, usually constructed of stainless steel or monel, have a speed up to 32,000 cuts per minute. Originally the machine was fed by hand, but later models use an automatic belt onto which the product is thrown. The machine is specially designed for citrus fruit peels, and will handle raw peel, quarter or half caps, cooked peel or peel from brine. It is practically impossible for a piece of peel to get through the blades without being properly cut. The thickness of the cut is determined by the numbered change wheels which can be adjusted in a few minutes.

(h) Shredding

Shredding machines are used principally in the manufacture of jelly marmalade. The citrus fruit peel is fed into the machine in quarter caps, whereby the white is removed and, at the same time, the orange skin shredded. The length of the shred depends upon the machine, but the width can be varied at will as well as the amount of white which is removed.

Vegetables are usually shredded prior to dehydration for use in soup mixes. For asparagus, the more tender butts are sometimes shredded for soup stock. Pumpkins and squash, after peeling and seeding, are shredded in a silage cutter or other form of heavily constructed cutting machine into pieces about $\frac{1}{4}$ inch thick. Cabbage is shredded by thin, curved knives attached to a revolving metal disk about 3 feet in diameter and housed in a vertical metal cylinder into which the heads of cabbage are fed. The shredded cabbage is removed by conveyor.

(i) Slicing

Because of the greater tendency of the consumer to purchase sliced fruits for dessert purposes, a greater portion of fruit is now sliced. Some products, such as onions, and tomatoes, are sliced prior to dehydration.

The peach-slicing machine consists of several circular, revolving knives above a rubber belt on which the halves, cup side down, are conveyed. A vibrating screen automatically places most of the peach halves in the proper position before slicing. Pineapple, after coring and trimming, is automatically cut into circular pieces by the knives of the slicing machine. Pimentos are cored and stemmed by a knife similar in construction to a peach-pitting spoon.

(j) Grating or Crushing

Before crushing and grating, fruits should be well washed with water to free them of dirt and insecticides. Stems, if heated with grapes, for example, impart a harsh flavor and therefore should be removed during disintegration.

Machines used for grating or crushing should be constructed of materials which do not react with foods. Iron and ordinary steel are very undesirable. Iron or steel rolls or knives may, by the dissolution of small amounts of iron which may react with the tannins and coloring matter of the juice, produce a black or dark brown

color. Stainless steel is very resistant to the action of fruit juices, and may be used for crushers, reamers, etc., if the output is sufficient to justify the expense. Copper and tin are objectionable because, even in small concentrations, their salts adversely affect the flavor and color of most juices and catalyze undesirable changes. Grape crushers should be made of resistant bronze or other alloy or metal not attacked by the juice.

Machines used for the grating or crushing of food products are varied according to the product being processed. For pineapple, a machine known as an eradicator is used: it is equipped with an adjustable knife set at an angle and with rollers which carry the fruit shells from the Ginaca machine below but against the knife. Most of the pulp is cut or scraped from the shells, and drops to a broad sorting belt. The pulp thus scraped from the shell is then grated or crushed. Peaches, pears, or apricots are coarsely ground, to produce sauces, in a large-sized food grinder equipped with a plate having $\frac{1}{2}$ -inch openings. Strained fruits are passed through a fine screen of a tomato juice extractor or a tomato cyclone. Corn cobs from cutting machines are carried by conveyor to the husk pile or to a cob crusher where they are crushed or cut finely enough to be mixed with husks for use as stock feed or silage. Usually silage cutters or roller crushers are used.

The crusher for grapes consists of two fluted metal rollers which revolve toward each other. These are adjusted at such a distance apart that the grapes, but not the seeds, are well crushed. Paddles revolving in a perforated cylinder below the rollers knock the crushed berries through the holes in the lower half of the cylinder and "kick" the stems out of the open end of the stemmer cylinder. In the Garrola crusher the grapes are crushed by impact against rapidly revolving paddles inside a perforated cylinder. The crushed berries and juice are pumped to a storage tank.

Apples are prepared for pressing by treatment either in an apple grater or in a hammer mill. The grater consists of a revolving metal cylinder about 8 to 12 inches in diameter; on the surface are imbedded shallow knives extending the entire length of the cylinder; parallel to the cylinder is a set of upright knives or curved, fluted metal plates toward which the cylinder revolves. The fruit passing through the machine is grated rather than crushed. The upright knives or curved plates are on heavy springs to permit the passage of rocks or other hard objects. The fineness of the grating is regulated by adjusting the distance between the cylinder and upright knives or plates. This apparatus is also fairly satisfactory for grapes, berries, and pears. Apples may be disintegrated in a special hammer mill. The hammers, consisting of flail-like pieces of metal attached to a revolving cylinder, crush the fruit finely by impact against a metal surface. The product from the hammer mill yields a larger amount of juice than the grated fruit because of the more thorough grinding of the fruit.

Edge runner mills are used in disintegrating olives in the preparation of olive oil. Apricots, peaches, and tomatoes are passed through some sort of a pulper to give a puree-like liquid containing, prior to juice separation, a large proportion of suspended, finely divided solids.

Citrus fruits require special equipment and procedure. Tomatoes are sometimes crushed by passing between revolving and fixed metal fingers that tear them coarsely. Berries and fruits, prior to the manufacture of jam and butter, are sometimes crushed in a machine similar to the Garrola crusher.

(k) *Shelling*

Shelling machines are used for removing peas from the pod after removal from the vines. The machines are made in various capacities, but the principle is the same in all: There is an outer hexagonal drum and an internal shaft to which beaters are attached; the drum is provided with projections on the inside so that, as it revolves, it carries the pods to a certain height, and as they fall they are struck by the beaters which revolve rapidly in the direction opposite to the drum; the impact of the beater upon the pod causes the latter to burst open and the liberated peas roll out through perforations in the drum; the pods gradually work through the end of the drum opposite to that from which they enter.

(l) *Viners*

These machines are usually used in connection with pea canning, to remove the peas from the pods. When a viner is used, the pea crop is mown and the vines are forked onto a mechanical conveyor which feeds them into the machine. The shelling is carried out by what is known as the impact principle, which opens the pods by forcibly reducing their volume. Since the pods contain air as well as peas, any distortion that lessens the space it occupies produces a pressure within, thus causing the pod to burst at the weakest point, where the two halves are joined. The peas pass out along the side of the machine, while the vines with the empty pods attached pass through and are rejected.

3. Separation

SCREENING

Screening is essentially a separation of coarse from fine materials. Size grading is a screening operation and is discussed elsewhere in this chapter (see page 14). Screening of threshed and milled cereal products is discussed on pages 451 *et seq.*

FLOTATION

(a) *Gaseous*

Dusts originating accidentally during milling operations or intentionally during separation or purification processes must be collected, not only because of the danger of dust explosions and health hazards, but also because of the economics involved. The simplest, but clearly the least efficient, means of dust collection is by blowers which transport the dust-laden air into a large, dust-tight room where there is a con-

siderable decrease in the velocity of the forward flow. If the room is sufficiently long, the air drops a greater portion of its dust before it escapes to the atmosphere. If the exit orifice is covered with a cloth panel, a still larger proportion of the dust can be recovered. In this case it may be necessary to beat the dust from the cloth filters occasionally to prevent undue retardation in the air flow.

A more popular modification which requires much less floor space and only slightly more labor for operation is the tubular-type dust collector. A series of cloth tubes supported by springs and situated on the top of a flue box disperse the dust-laden air to the atmosphere and simultaneously remove the dust from the air by filtration. The dust is removed from these tubes by jarring with a hammer while the air current is shut off from the section being cleaned. Usually a counter or reverse current of air is drawn through the meshes while the jarring takes place, and much of the dust embedded in the meshes of the cloth is carried to the discharge conveyor. This procedure aids in keeping the filtering surface of the cloth tubes free and open for the air filtration. If the dust-laden air contains considerable moisture, the cloth tubes will soon become clogged, necessitating their removal and thorough cleaning.

Properly designed cyclone dust collectors are very efficient but considerably more costly than the types discussed above. The cyclone dust collector makes a gravity separation of the dust from the air by means of a centrifugal force after the air has been expanded to reduce its velocity and pressure. The size and design of this kind of dust collector depends on a number of factors:

- (a) The amount of dust to be collected.
- (b) The moisture content of the dust.
- (c) The size, speed, and capacity of the fan.
- (d) The relative sizes of the inlet and outlet orifices.
- (e) The nature and gravity of the dusts.
- (f) The volume and pressure of the air currents.

When these factors are correctly proportioned, the machine operates with high efficiency; otherwise the machine is likely to become a dust distributor rather than a collector. Even under optimum operating conditions some dust escapes; but the amount may be reduced by discharging the air into a simple settling chamber which in turn is vented to the outside of the building. A still more efficient but more costly installation consists of discharging the air from several collectors into an independent fan which discharges into an independent collector.

A newer type of dust collector, the electrical precipitator, has not yet been extensively used in the food industry. The machine consists of one or more vertical tubes in which a wire is supported in the exact center yet is well insulated from the tube. The wire is attached to one pole and the tube to the other pole of a very high, direct current voltage obtained by a specially constructed rectifier. The dust-laden air passes through the tube; the charged dust particles are attracted to the charged tube where they are held by electrical attraction, while the air, gases, and vapors pass out into the atmosphere. The tube, obviously, must be charged oppositely to the dust

particles. The collected dust is removed from the tube by shutting off the current and pushing the dust down by means of a brush or scraper, although in some cases the removal or reversal of the charge is sufficient. This type of dust collector is very efficient and is recommended not only as a dust collector but also for installing in chimneys to precipitate soot and coal fines from smoke. Since the operation is only slightly affected by temperature, the device can be installed directly in the chimney in those communities having smoke abatement regulations.

(b) *Liquid*

Mixed materials of differing specific gravities may be separated by placing the mixture in a liquid of such density that one of the products will float while the other sinks. Water or dilute brines are used as a separating liquid when this technique is employed for separating frozen from sound oranges, overmature peas from green peas, and apricot hulls from kernels after crushing of the pits. The same technique is used in milling wheat by the Earle process which is discussed on page 490.

SEDIMENTATION

As the name implies, this is a process in which a liquid food product is allowed to clarify by settling of the sediment, after which the clear liquid can be drawn off.

(a) *Simple Clarification*

Sometimes settling can be facilitated by a preheating treatment which coagulates proteins and other heat labile components. At times the coagulated proteins occlude other sediment and thus remove it. In some cases the sediment forms on the surface and may be removed by skimming or by centrifugal treatment. In others, such as in the preparation of sorghum sirup, the clarification is accomplished by settling in tanks or barrels of suitable size or by slow flow through long, shallow tanks equipped with baffles which retain the sediment or floating materials. Shallow tanks from 1 to 3 feet deep are sometimes used to clarify certain jelly juices, the shallow tanks being necessary because of the slow settling rate of the sediment.

Olive oil and similar substances may be separated from the juice or black liquor by settling in tall, cylindrical, tin or galvanized iron tanks of a capacity of 300 to 800 gallons, constructed with conical or sloping bottoms so that a sharp separation may be obtained. The oil is washed by spraying warm water on the surface or by spraying the oil in water at 90 to 100° F. and allowing the oil to separate from the wash water by sedimentation. The washed oil is cloudy and still contains some pulp and emulsified water. This material, along with excess solid fats, is settled out during 10 or 12 days' storage in the tall cylindrical tanks. The settling or "foots" are drawn off and sold as soap stock or reworked. This equipment can be arranged for continuous operation.

Even under optimum conditions the settling rate is slow, in the case of most food juices, and the time interval involved permits many undesirable changes to occur; in most instances other clarifying means are used.

(b) *Fining Agents*

Fluid food products may be clarified by any of the these procedures, but treatment with fining agents followed by filtration (see page 30) is generally preferred because of the time element involved. Settling in general, but especially with fining agents, yields brilliantly clear products.

Some fluid food products which do not settle and which are difficult to filter may also be clarified by the use of fining agents. Such an agent may be defined as one which, when added to the material to be clarified, will precipitate in a form which settles rapidly and which in its precipitation will carry the suspended matter down with it. Such an agent must be so chosen that it does not adversely affect the food product or its storage properties. The mechanism of its function may fall into one or more of the following categories: coprecipitation; mutual electrical attraction; base exchange; mechanical. The fining agents most commonly used include egg albumen, casein, Spanish clay, bentonite, animal isinglass, gelatin, and various filter aids with or without heat treatment. Enzyme treatment is also sometimes employed. The amount of fining agent to be added varies within wide limits even for the same product, but is roughly proportional to the amount of suspended material. The amount of agent to be added must be determined with a small test batch before treatment of the larger batch.

Dried Egg Albumen or Fresh Egg White.—Dry granular egg albumen, which may be purchased as such, or fresh egg whites may be used with equal efficiency. Enough of the dried egg albumen to make a 2% solution is soaked and agitated in warm water at a temperature sufficiently low to eliminate danger of coagulation. After the dissolution is complete, this solution is poured slowly into the material to be clarified and the mixture stirred vigorously to insure thorough mixing. After treatment the product is heated to a temperature of 160 to 175° F., *i. e.*, at a temperature above the bottling temperature. This heat coagulates the albumen so that it settles during subsequent storage. The temperature must be sufficiently high to avoid clouding of the bottled product. The settling of the coagulated albumen may take several days or may be completed within a few hours, depending upon the nature of the product being clarified.

Casein.—A specially prepared casein which is soluble in liquid food products is commercially available; but ordinary dry casein may be used if soaked in dilute ammonia (1:20) and then boiled until ammonia fumes are no longer detectable. This solution is diluted to 2%, added to the liquid to be clarified, and the whole agitated until mixing is complete. The acidity of the juices precipitates the casein, the coagulum settling rapidly within 24 to 48 hours after pasteurization. Casein is less

likely to cloud the product after bottling, but it does exert a bleaching action on certain colored juices which can be prevented somewhat by the simultaneous use of tannin.

Spanish Clay.—The clay is soaked for about a week in water in 10% concentration. This mixture is added to the liquid to be clarified and thoroughly mixed. The product admixed with clay is heated to 140° F. or higher to facilitate coagulation and settling.

Bentonite.—This is a clay which is rapidly gaining wide acceptance in the food industry in many surprising uses, although considerable care must be taken to insure that it does not impart an off-taste to the product. Bentonite is one of the few fining materials suitable for fining jelly juices. It is prepared by sifting the powder slowly into water or some other fluid with vigorous stirring; this mixture is stirred until a smooth creamy suspension results which is adjusted to about a 5% concentration; it is then poured into the liquid to be clarified and mixed thoroughly. The coagulum settles rapidly, although heating the mixture to 140° F. or higher facilitates the rate of coagulation and settling. Bentonite can be used to advantage following fining with casein or in case of overfining with other materials.

Animal Isinglass.—This fining agent is best for wines. The fining solution is prepared by a soaking overnight in a fluid acidified with citric acid, followed by grinding and rubbing through a fine screen. (Optimum results are obtained by soaking it in the cold, although the fining solution is more easily prepared by soaking it in the warm liquid.) Prolonged soaking in a sulfited citric acid solution is also practiced. The isinglass solution is added slowly to the liquid with vigorous agitation. A very light and fluffy sediment is formed, and care must be exercised to avoid stirring it up during separation.

In order to precipitate the isinglass and thus carry out its clarifying function, tannin equal in weight to the amount of isinglass used should be added; the isinglass is simultaneously removed during the clarifying process.

Gelatin.—In fining with gelatin only the better grades of edible gelatin free from objectionable odors and flavors should be used. Suitable grades are available in powdered, granular, or sheet form. A solution of about 2 ounces per gallon is prepared in hot water, added to the liquid to be clarified with agitation to insure good mixing, and allowed to settle. An equal weight of tannin should be added; gelatin, like isinglass, removes tannin during the clarifying process. The tannin should be added several days before the fining agent is added.

Gelatin and most nitrogenous fining agents combine with, or are coagulated by tannin. Their use decreases the tannin content of wine, and in the case of casein and gelatin causes a noticeable decrease in color. Egg albumen and isinglass have less tendency to remove color, and as noted, the addition of tannin will also aid in preventing the bleaching action of casein, or of gelatin.

Filter Aids.—A treatment with 1 to 5% filter aid followed by heating and settling is suitable for some food liquids.

(c) Enzymes

Some food liquids may be clarified by treatment with a pectic enzyme complex marketed under the name of "Pectinol." This enzyme complex was isolated from a strain of *Penicillium*, a mold. The enzyme is added to the fresh juice and allowed to act for 24 hours during which time the pectin in the juice is hydrolyzed and precipitated as pectic acid. The liquid so clarified must be pasteurized before bottling to destroy the enzyme; otherwise a deposit will form in the bottled juice. Enzyme-treated cider has a very fine appearance, but there is a tendency for the product to be thin, and lacking in flavor and the delicate afterflavor. However, the unclarified juice tends to deposit sediment which spoils the appearance of the product for bottling.

FILTRATION

(a) Materials of Construction

Regardless of their design, filters should be chosen on the basis of their effect upon the quality and storage properties of the product to be filtered. In general, corrosion-resistant alloys or rubber-coated steel or plastic are most satisfactory. Iron, tin, copper, and the like are particularly objectionable, as minute amounts dissolved in the juice cause clouding, loss in color, and undesirable changes in flavor, as well as oxidative destruction of vitamins. Aluminum corrodes rapidly, although aluminum bronze has proved very satisfactory because of its resistance to corrosion and because it has sufficient strength. Iron or galvanized iron is suitable for many food products but not for all. Nickel- and chromium-plated equipment is generally used although the latter is usually required in processing acidic foods.

(b) Filtering Mechanisms

Bag Filters.—The simplest form of filter is the jelly bag through which the housewife filters juices prior to making jelly. Its industrial counterpart consists of a conical bag made of canvas, felt, or some other heavy fabric. Often this type of filter is useful for a preliminary treatment of a juice to be clarified later by more effective means. Unless the juice is mixed with a suitable filter aid it does not usually yield a clear juice. Olive oils filtered through a bag filter yield a clear oil freed of most of the water and solid impurities.

Strainers.—Milk strainers and paper filters are other forms of simple filters. In the final purification of olive oil, for example, in order to produce a brilliantly clear product, the oil is filtered through folded filter paper in tin funnels. Sugar sirups are usually filtered through a milk strainer type of filter before being canned.

Pulp Filters.—The usual form of pulp filter consists of upright copper or stainless-steel cylinders which are filled with several thick disks of compressed wood or cotton fibers. Circular metal screens or metal plates are placed between the pulp disks, and the fluid inlet and outlet lines are so arranged that each disk acts as an individual filter. The fluid is forced through the filter by gravity from a supply tank.

above the filter or by means of a force pump. The pulp must be removed occasionally, washed clean, and replaced for re-use. The clarity of the filtrate and the rate of filtration depend to a large extent upon the pressure applied in forming the filter cake. In general, the filtrate will be clearer and the rate of filtration slower under higher filtration pressure.

A simpler, widely used pulp filter consists of a large suction funnel attached to a large filter flask or to a bottle and suction pump or aspirator. This setup is satisfactory for small-scale filtration. Filter paper pulp, asbestos or other pulp is suitable for the filtering surface. The clarity of the filtrate is governed by the fiber length, short fiber with asbestos flour and filter aid producing a slower filtering mat but yielding a brilliantly clear filtrate. The mat is easily washed and may be used repeatedly.

The Seitz filter is of this same general type. It consists of an upright chamber in which is enclosed a screen coated with a layer of asbestos fiber or other pulp. This kind of filter is constructed for a large capacity as well as for the usual size. In general, it has a large capacity and may be used for bulk or preliminary or postfining filtration.

Another form of pulp filter, used by the wine industry, consists of a perforated cylinder placed within a larger cylinder usually constructed of copper. Suitable pulp is packed by hand in a layer over the perforated cylinder, and the wine to be clarified is forced through this layer. The filter is inexpensive, easily operated and cleaned, and produces a fairly satisfactory filtration.

Pad Filters.—Pad filters have found recent popularity in the food industry. They consist of a number of recessed metal frames between which are held thin pads composed of pulp and asbestos fiber. They are obtainable in varying degrees of porosity and must be discarded after use. A preliminary filtration usually precedes pad filtration. Fruit juices may be preserved by filtration through a "tight" pad; but pasteurization is still more suitable.

Pad filters are usually of small capacity. They are customarily employed for final filtration when a brilliantly clear product is desired, since the pads are rather costly and can be used only once. The introduction of iron and copper salts from the filter pads, filter aid, or filter mass is sometimes an important cause of cloudiness in wines and other liquids.

Filter Press.—The usual filter press consists of a series of metal, wood, plastic, or rubber-coated grooved plates and open frames arranged alternately on a press rack and between which are placed filter cloths or canvas so that each combination of one frame and one plate surface acts as an independent filter.

All of the frames are pump-fed from a common supply. The liquid filters through the cloth into the grooves of the plate. The filtered juice leaves the press plate by means of a spigot, which functions as a cutoff valve in case a cloth breaks or otherwise permits the cloud to pass through the cloth. In such cases the offending filtering surface is shut off and the filtration continued with the other filtering surfaces until the frames are filled with residue, at which time the pressure in the system rises

rapidly. In actual operation, the liquid to be clarified is usually mixed with a small amount of filter aid, which collects on the cloth surface and decreases the porosity, resulting in an effective removal of the suspended matter.

Filter pressing is much less wasteful than the skimming method used in the clarification of cooked jelly juices. Usually 0.10 to 1.0% filter aid is added. The filtration is then fairly satisfactory, since the filter aid, forming a nonpacking layer on the filter cloth, prevents sliming or clogging. The juices must be filtered before the addition of sugar because the increased viscosity after sugar addition makes the filtration too slow or even impossible. If the juices require concentration by boiling before the addition of the sugar, this should be done before filtering because of the possibility of heat coagulation of various organic materials which must be removed before sugar addition. Olive oil is mixed with a small amount of filter aid and filtered in a filter press using filter paper in place of filter cloth.

Another form of filter press consists of a hollow, clamshell-shaped disk covered with heavy cloth and housed in a metal box. The liquid is mixed with calcined filter aid prior to filtration. Still another type, which is simple to operate and has a large capacity, consists of several fine-meshed screens suspended in an enclosed cylinder. A filtering surface is built up on the screen by pumping a mixture of the liquid and siliceous earth through the filter. The screen catches and retains the siliceous earth forming the filtering surface.

Candle Filters.—Candle filters consist of several large, unglazed porcelain tubes closed at one end and placed in a closed metal chamber. The fine pores of the porcelain act as a filter, the porosity of some candles being fine enough to remove all the microorganisms. Such filters are used very generally for a final polishing filtration prior to bottling.

Centrifugal Filters.—Centrifugal filtration is used throughout the food industry. In settling, the rate is governed by particle density, viscosity of the medium, and other factors, but the action of gravity may be enormously increased by the application of centrifugal force. The centrifugal force depends principally upon the peripheral velocity of the centrifuge, and, to a lesser extent, upon the diameter of the basket. Some commercial centrifuges may be operated at up to 40,000 revolutions per minute, which increases the pull of gravity several thousand times. Thus a settling which sometimes requires several days is effected almost immediately. Some centrifuges are continuous in operation, while others are intermittent and must be cleaned as soon as the basket is filled. Prior filtration improves results obtainable with centrifugal filtration, in that it prevents too rapid clogging of the bowl of the clarifier.

(c) *Filtering Factors*

Fresh juice and saps contain a large amount of finely suspended solids which are rather slimy in character and extremely difficult to filter. Preliminary pasteurization denatures the protein moiety of the solids and thus reduces the viscosity of the liquid. The following 1 to 2 days' settling usually results in coagulation of much

of the protein, which, while settling, carries with it a large proportion of finely divided pulp, thus enhancing the filtration.

Ordinary filter aids are likely to impart a disagreeable flavor to the juice. Calcined filter aids, however, have been shown not to cause off-flavors to develop. An amount up to 6 pounds of such a filter aid mixed with the product to be clarified has been found satisfactory. A thick layer of filter aid should be built up on the filtering surface to prevent its clogging or sliming by the suspended solids. This layer also has the function of reducing the porosity of the filter to yield a very clear juice.

In most food products, the filtrate is the valuable portion. In cases in which the residue is the valuable part, the use of filter aids is eliminated.

Undue aeration must be avoided in the filtering of fruit products which have not been heated to destroy oxidative enzymes, since aeration coupled with enzyme action would cause the destruction of vitamin C and would cause very rapid oxidative flavor changes. Such difficulties are mainly encountered in citrus, apple, tomato, and similar juices. However citrus and tomato juices are not filtered.

BASE EXCHANGE

Base-exchange methods are utilized in the manufacture of several food products to remove destabilizing ions like calcium and magnesium and replace them with stabilizing ions like sodium and potassium. See page 812. The product to undergo base exchange is forced by gravity or pump into the bottom of a column or bed of zeolite or other base-exchange material until its exchange capacity is exhausted. After washing the zeolite with water, a mixture of dilute acetic acid, sodium chloride, and potassium chloride is passed through the column to regenerate it (replace the calcium and magnesium with sodium and potassium). After another washing with water, the column is ready for use again.

Lyman and coworkers have applied this process to the treatment of milk in order to produce a highly nutritious infant food. Only the ionized portion of the calcium and magnesium is removed from the milk, leaving in the treated milk about four times the calcium content of human milk. Cow's milk so treated will produce a very soft, easily digestible curd in the stomach, while untreated cow's milk will form a firm, hard, slowly digestible curd. Milk treated with base-exchange materials may be evaporated or powdered, and can be used to advantage in the manufacture of concentrated ice-cream mixes. The treated milk is marketed under the name of "soFKURD."

CONCENTRATION

(a) *Distillation*

Concentration by separation based on differences in volatility is known specifically as distillation, and is effected by means of a still the size and design of which varies according to the nature of the product. Alcohol and essential oils are separated in

this manner. Immediately following the still, there is usually a rectifying column through which the vapors pass. The rectifying column is not necessary in the processing of all food products. When used, the column is maintained at such a temperature that the various components are condensed at various points along it, and may be removed or may be returned to the still. In the case of an alcohol still, each section of the rectifying column is an additional still so that the vapors entering the condenser consist of about 95% alcohol and 5% water. Following the rectifying column is a condenser in which the vapors are condensed again.

Some products may be distilled by direct application of heat to the still; but others can be distilled only if a current of steam is passed through the material. For example, the ground press cake from whole oranges or lemons or the ground gratings from mechanically peeled oranges or lemons may be distilled in a current of steam to recover the oil not removed by other means; the resulting oil is water-white, is much inferior to cold pressed oil in color and flavor, is very unstable, and deteriorates rapidly unless held in cold storage. Steam distillation *in vacuo* yields citrus oils superior in flavor and keeping quality to that obtained by steam distillation at atmospheric pressure.

(b) Concentration at Atmospheric Pressure—Boiling

Boiling is one of the most important steps in the food industry and is used not only for concentration but also for dissolution of additions and for cooking. Prolonged boiling must be avoided because there is a loss in flavor, injury to the color, and hydrolysis of various components. The aroma is changed or lost completely and many mineral salts are precipitated. Denaturation and agglutination of proteins and other organic components during boiling produce a scum which is generally removed by skimming or filtration. Many of these troubles may be eliminated by means of vacuum concentration, which is discussed below. Since some can be minimized by rapid concentration, the equipment chosen should give a maximum concentration in the shortest possible time.

Materials of Construction.—The materials of construction of the concentrating apparatus play an important part in the quality of the food product produced. For example, direct contact with copper, tin, iron, or zinc causes the red color of grapes to turn brown or precipitate and will impart a metallic taste to the product; a glass-lined pan with a steam jacket and flash coil of aluminum or other metal insoluble in the juice is satisfactory. Copper is less objectionable than tin; and either stainless steel or glass-lined equipment is the best for the purpose. Copper kettles with or without tin or silver plating are used in the manufacture of jelly; but here, too, stainless steel, nickel, monel, and aluminum, since they affect the color and flavor less, are all preferable to tin, copper, or silver. Cypress kettles are also used. Glass-lined steel is becoming more popular because the smooth enamel coat is more readily cleaned than are wooden tanks, which because of the difficulty encountered in cleaning, often impart a musty or moldy flavor to the product. Nickel- and chro-

mium-plated equipment are used throughout the food industry, the latter mostly in the processing of highly acidic foods. Aluminum, though limited in use, has a very definite value in the manufacture of meat and meat products. Mild steel is used in processing several meat products, especially corned beef. Wood is used in some cooking and hot pickling where constant boiling obviates the danger of bacterial infection, although resinous woods are avoided because they impart a taste to the product.

Iron Kettle Cooker.—The simplest cooking method consists of an iron kettle heated on a firebox in which wood or some other material is the fuel. Products concentrated by this method are usually caramelized severely and darkened by overheating as well as by the iron salts entering into solution through the action of the juices upon the kettle. Smaller kettles are much preferred to larger ones in which the boiling process is unduly prolonged.

Sugar Cooker.—Gas-fired sugar boilers are still used to a great extent in hard boiled sugar work to attain that extra degree of heat unattainable with steam pans. The color of the cook is of prime importance and the selection of an efficient stove imperative, since poor results are due to the shape of the pan and irregularity of the heating. Some of the pans are oval; when placed on the fire the extreme bottom dips deeply into the fire and is thus subjected to a more intense heat; but as the batch reaches the correct temperature the bottom portion of the cook becomes too viscous for convection currents to carry the heat, and the batch thus has a tendency to burn and become discolored. The fire itself has certain disadvantages in that the forced draft causes irregularity in the distribution of the heat and a tendency for local overheating to occur. New types of burners have since been devised to overcome the disadvantages of older heating methods.

Surface Combustion Burners.—Surface combustion burners are more efficient, utilize more economically the heat value of the gas, and are unique in compactness of construction. Here, the oval pan is replaced by a round bottom pan. The basic principle of surface combustion consists of mixing gas with air and passing the balanced mixture through a porous refractory medium. The mixture is ignited on the opposite side of the refractory and burns without flame. Complete combustion is assured without taking oxygen from the surrounding air. The surface of the porous refractory becomes highly incandescent, so that radiant heat is evolved.

Cox Burner.—The Cox burner is one type of combustion burner in which the whole bottom of the burner is covered with porous brick. Gas and air are controlled by special tap valves to insure maximum heating efficiency and maximum economy of gas consumption. In lighting the mixture, the whole bottom of the burner becomes red hot almost instantly with no visible flame. Local overheating and spot heating is thus avoided. The pan used with this burner has a round bottom which exactly fits the stove so that every part is equidistant from the source of heat. This type of construction permits more rapid boiling with little fear of burning, and thereby insures a more even cook. The Cox burner is very efficient in that superfluous construction, such as massive iron casing and excess firebrick, is eliminated, for excess

construction requires considerable gas to heat it before the product starts cooking. The Cox burner saves 12.5% or more of the gas and usually shortens cooking time.

Sorghum Pans.—Sorghum pans, which are extensively used for maple, cane, sorghum, and other sirups, represent a great improvement over the direct-fired kettle. They are shallow rectangular pans 4 to 6 inches deep, 6 to 15 feet long, and divided crosswise into sections by thin strips of metal staggered in a manner to give a zigzag itinerary to the liquid during concentration. The pan sits upon a firebox from which it may be lifted to permit cleaning. The operation is continuous in that the liquid enters at the fire end and concentrated syrup is drawn off at the chimney end. The rate of flow is so adjusted that the sirup reaches the desired concentration by the time it flows from the cooker. The shallow layer permits a more rapid concentration and gives a lighter colored product with less scorched flavor. Skimming may be necessary to remove the coagulated proteins, etc. Some manufacturers use two pans, the first to effect a preliminary concentration followed by a filtration for clarification, and the second to complete the concentration.

Steam Pans.—Steam-heated pans are used generally in the food industry. The designs employed are nearly as numerous as the food products prepared, each design having certain advantages. One type, perhaps the simplest, consists of a long, shallow, open wooden box lined with copper or tin, in which the liquid is boiled by a closed, removable, steam coil extending the full length of the evaporator. In this evaporator the coil is covered to a depth of about 1 inch; its operation is identical with that of the sorghum pan described above, but with less danger of scorching since the rate of concentration can be more accurately controlled. Apple, pear, and similar juices are concentrated in similar pans constructed of stainless steel.

Steam-jacketed kettles and pans are more generally used in the food industry than any other concentrating device, although there is still danger of getting a dark product with a scorched flavor. Some kettles are heated by closed coils, known as flash coils, which usually have a diameter of about 3 inches. This relatively large diameter gives a large heating surface, and allows free passage of steam and a rapid and uniform heating of the coils, so local overheating and sticking of the pulp are reduced to a minimum. Such a coil will, under normal conditions, reduce 500 gallons of tomato pulp to 250 gallons in 35 to 45 minutes or less. In order to prevent foaming and the sticking of the pulp to the coils, some manufacturers add a small amount of vegetable oil to the empty kettle so that, as the pulp rises during filling, the sides of the kettle and the coils are coated with oil. Foaming can be controlled by careful heating and by an occasional spraying of the surface of the boiling pulp with water. As soon as the coil is covered, the steam may be admitted and concentration begun. During the first stages, the coils must be well drained to prevent filling with water, a condition which favors scorching.

Jam Pans.—Jam pans are special jacketed kettles operating with a larger steam space and constructed to operate at high steam pressures. Since the metal making up the pan and jacket must be rather thick because of the pressures involved, insurance companies place considerable emphasis on this point. Operating at pres-

sures of 70 to 100 pounds per square inch or higher, coupled with a larger steam space, gives a quicker boil and a better colored product.

Continuous Cookers.—Continuous automatic sugar cookers have been developed for the candy and cake industry for the production of a clear white sugar boil in the shortest possible time. In this operation, the liquid is in contact with the heat for only 8 to 10 seconds, and a heavy syrup is produced. The apparatus consists of a steam-jacketed tube containing a hollow tapered spiral of gun metal. The syrup is forced through the machine by a pump, the stroke of which is controlled by a slot-link control. By increasing the stroke the flow of the syrup is increased and the heating time lessened; by decreasing the stroke the flow of the syrup is cut down and the heating time increased, thus giving excellent control over the operation. The syrup enters the machine in a thin film at the top of the spiral and swirls downward, while being subjected to the heat action from the outer steam jacket operating under a steam pressure of 120 pounds. At the bottom of the spiral is a chamber in which the flow of the syrup is momentarily retarded so that the moisture from the sugar syrup can escape through the center of the spiral. The cooked syrup flows through a check valve over a thermometer onto a revolving cooling table, from where it is removed, when at the correct consistency, to drop rollers. About 400 to 800 pounds of syrup are cooked per hour. The main advantage of this cooker is that any sugar or combination of sugars may be used.

(c) *Solar Concentration*

Solar concentration is used for small-scale concentration in regions with a sunny climate. The liquid to be concentrated is placed in a pan or tank and a cheesecloth dipped into the juice and hung above the tank to dry. During the drying, water is removed by solar concentration and the concentrated solution remains on the cloth. The cloth is then wrung out, dipped in the juice again, and dried. This operation is repeated until the liquid in the reservoir has reached the desired concentration. The product obtained has a brown or dark amber color and a pleasing flavor.

(d) *Spray Concentration*

Spray concentration is extensively used in those processes having considerable waste heat and a product not affected by aeration. A tank containing the liquid to be concentrated is connected by pump and pipe to spray jets at the top of a tower sitting in the tank. Suitable blowers force the hot air into the bottom of each tower. The air rises against the liquid spray and, exhausted of moisture and heat, escapes from the top of the tower. The liquid to be concentrated is recirculated through the tower until the desired concentration is reached. If the heat of the air is not exhausted during the rise through one tower, several towers may be used in series with the weakest solution being passed over the lowest temperature tower and the strongest solution being passed over the highest temperature tower. The towers are usually

constructed of cypress; the method furnishes an effective way for recovering waste heat.

(e) *Concentration by Freezing*

Freezing concentration has been used for concentrating cider and sirups in a barrel allowed to stand out of doors until partially frozen. Large ice crystals extend from the sides of the barrel toward the center. The unfrozen concentrate remains in the center. The barrel is then opened, and the concentrate withdrawn and further processed by heating. Some smaller factories still preconcentrate by this method.

Since, theoretically, six and one-half times as much energy is required to evaporate a pound of water as is required to freeze it, freezing should be more economical. In practice, however, present freezing methods of concentration have proved to be more costly because of the indirect utilization of fuel energy, for fuel is converted into steam, then into electrical energy, and finally into refrigeration. With current processes, the amount of handling of the product necessary to effect the concentration is unfavorable.

In the Gore process, the juice is placed in a freezing room or in an ordinary ice can surrounded by cold brine where it is frozen to a mushy mixture of ice crystals and dilute sirup, or to a solid cake. The ice is then crushed in an ice crusher and placed in an open-basket centrifuge operated at moderate speed. The basket is a perforated cylinder attached to a vertical shaft and surrounded by a heavy metal wall. The centrifugal force developed by the whirling of the basket forces the sirup through the perforations, while the ice remains in the basket where, while the centrifuge is still whirling, it may be washed free of sirup by means of a spray of ice water. The sirup is collected in the outer chamber and flows from the centrifuge through a suitably arranged outlet. The centrifugate is frozen one or more times again at successively lower temperatures and reprocessed to raise the concentration. In the case of maple sirup, the concentration is raised to 29° Bé.; to prevent spoiling the sirup must be kept in cold storage or else pasteurized.

The Monti process is very similar to the Gore process except that the ice is separated by draining. At Ohio State University, a new continuous process has been developed which eliminates the troubles inherent in the others.

Juices and saps concentrated by freezing possess a richer fresh flavor than those produced by any other known means of concentration.

(f) *Concentration at Pressures below Atmospheric—Vacuum*

Many of the troubles encountered in open boiling may be minimized, or even eliminated, by vacuum concentration because the boiling point is reduced by as much as 100° or more. Thus, high temperature effects such as caramelization of the sugars, excessive losses in flavor and aroma, production of off-colors and other thermal effects, and decomposition are avoided. It is, however, a popular misconception that less heat is needed for evaporation under a vacuum. Whether under a vacuum or under

atmospheric pressure, the heat required is that necessary to bring the liquid up to the boiling point plus the heat of vaporization. Since the latter is almost seven times the former, the amount of heat required does not change much under vacuum processing. The only apparent saving is the heat required to raise the temperature of the liquid to its boiling point.

The apparatus generally used in vacuum concentration consists of a boiling chamber fitted with vacuum pumps, condensers, and other auxiliary equipment. The boiling chamber is that part of the apparatus in which the liquid is heated. It is usually cylindrical, is fitted at the bottom with a steam jacket, and contains large steam coils or tubular calandria to heat the liquid. A large opening at the top in turn is connected to a vapor condenser and vacuum source. The walls must be sufficiently heavy so that they do not collapse when the vacuum is applied. The bottom must be much heavier in order to withstand the steam pressure and the vacuum.

The calandria is the most common heating device used in vacuum pans. It consists of a series of vertical steam-jacketed metal tubes which are open at both ends and joined by heavy metal plates to form a honeycomb structure. The tubes are filled with liquid as well as the space beneath the calandria. The liquid is heated by contact with the tubes. For ordinary concentration, steam is used in the jacket and coils or calandria, but in the case of delicately flavored juices hot water or steam at less than atmospheric pressure is employed.

Many types of vacuum sources are used: wet vacuum pumps, dry vacuum pumps, steam pumps, and water jet pumps.

Condensers and means of removing condensed water are also generally used. When jet condensers and surface condensers are used, the water is removed by a barometric condenser.

Many food processors use multiple-effect evaporators in which two or more pans are connected in such a manner that vapors from the first pan pass through the heating system of the next, whose vapors pass through the heating system of the next, etc. The first evaporator has the highest temperature and the lowest vacuum while the last evaporator in the series has the lowest temperature and the highest vacuum.

Concentration *in vacuo* causes considerable loss in the aroma of some fruit juice; but it is possible to collect the distillate, which is fractionated to concentrate the aroma, and then added to the concentrated juice. The Serolian process depends upon this principle.

The degree of concentration may be controlled by a number of ways: by concentration to a definite volume; by determination of the specific gravity; by determination of the refractive index; and by guesswork. Control by refractometer is generally accepted as being the most accurate.

CRYSTALLIZATION

Crystallization depends upon the concentration of solution to the point of supersaturation, at which point the solute separates in the form of small crystals. As the

concentration proceeds or as the solution is cooled, the crystals grow. They usually separate out as pure crystals; but if they entrain any of the mother liquor and its impurities, they must be redissolved and recrystallized. Sometimes agitation during crystallization is necessary to avoid the formation of large crystals. At other times just quiet standing is necessary. The temperature at which crystallization occurs is a peculiarity of the product: some crystallize from hot solutions, some from warm solutions, and some from cold solutions.

LIXIVIATION OR DIFFUSION

This process is used mainly by the manufacturers of beet sugar. The sliced beets are surrounded by warm water in a series of tanks known as a diffusion battery. The sugar diffuses through the cell walls of the beets into the surrounding water, which is then drawn off and concentrated. The same principle, which may be applied to other vegetables and fruits, is based on the phenomenon of osmosis.

EXTRACTION

(a) Solvent

Sugar, alcohol, and similar substances may be separated from fruit pomace and other food residues by water extraction, while fats, oils, and fatty materials may be separated by fat solvent extraction. In some cases the separation may be accomplished by use of expellers. For the extraction of juices, fruits are usually first crushed, although many (such as apricots, peaches, and citrus fruits) require only pressing.

The method of extraction depends upon the structure of the fruit, position and character of the tissues in which the juice is located, and character of the juice itself. In some food products, the juice is distributed throughout the pulp. In others, the tissue containing juice is surrounded by a thick skin which has soluble substances of objectionable flavor or color; these raise the problem of extracting the juice without also extracting undesirable substances: in some cases, the product is crushed or ground before extraction; in others, the product is subjected to a heat treatment prior to extraction.

(b) Pressure

The rack and cloth press is one of the most satisfactory types for extraction by pressure. The crushed fruit is piled in the center of a heavy, coarsely woven cotton cloth to a depth of 2 or 3 inches. The edges of the cloth are folded toward the center and a wooden rack constructed of heavy hardwood slats placed on top the folded cloth. The next cloth, containing fruit pulp, is placed on top this rack, followed by still another rack, and so on, until the press is filled. Pressure is then applied in accordance with the product being processed.

The basket press, as the name implies, consists of a heavily reinforced, cylindrical, hardwood slat basket. The whole or crushed fruit is usually put in one or more

heavy cotton bags and placed in this basket. As the pressure is applied the juice is expressed, flows between the slats, and is caught in a basin in which the basket sits.

The pressure may be applied to these presses by means of a lever arm, screw, or hydraulic pump, the latter being the most efficient.

Continuous presses have been designed in which the fruit is fed into one end, either crushed or whole, and transferred by means of a screw conveyor into a heavy cylinder or cone with a perforated bottom or a cylindrical cage. The pressure is obtained by adjusting the restricted outlet at the discharge end. The juice escapes while the mass is en route through the cylinder or cage and is caught by a funnel-like jacket. There is a considerable tendency in these machines to grind some of the fruit to a fine pulp which also passes through the press openings. The press is adaptable to many extraction processes, the cage extractor or expeller being used extensively in the separation of fats and oils.

The press cake or pomace may be disintegrated and pressed again; but usually the second pressing yields a very inferior product, darker in color and having an undesirable flavor. In some cases an excessive amount of tannin may be extracted. This will occur if the product is heated prior to pressing and the time-temperature relationships are not suitably balanced.

Other continuous presses of variable design are used. One type consists of a revolving member which crushes the fruit against a serrated surface, after which the juice and pulp are separated by fine sieves. This kind of press is very powerful, vertical, and continuous in operation.

Some materials give a very fine product when pressed first in the cold, while subsequent pressings are made hot to increase the yield. Care must be taken in mixing the products of cold and hot pressings, or the reduction in quality of the product may offset the advantage of the higher yield. Usually one or two cold pressings are mixed to give a salable product, and the second or third (hot) pressings are kept separate for utilization in other ways.

In the case of citrus fruits, either the whole fruit may be crushed and the oil separated by means of a centrifuge, or the surface may be grated or shaved off by means of a safety-razor type of attachment and then pressed. The peeling may be pressed by running through rollers. The pressing of the grated or shaved peeling gives a higher quality product. The pressing of the whole fruit followed by centrifugal separation yields a product of lower citral content, for the juice dissolves a certain amount of the citral from the oil. Citrus fruit oils cannot be successfully extracted by the use of volatile solvents with the methods now available.

4. Mixing and Blending

While mixing and blending are most important there is little standardization of these procedures in the food industries. This is most unfortunate. The standardization of product quality depends to a great extent upon proper mixing and blending under easily duplicated conditions. These operations are illustrated by the following specific examples.

(a) Conching

Conching is applied in the manufacture of chocolate and similar products to produce a very marked effect on appearance and flavor. It removes moisture, producing a mellowness; it brings out the full flavor of the cocoa; and it eliminates the harshness and acridity characteristic of raw cocoa. Conching blends the mixture of sugar, cocoa, and butter into a practically homogeneous mixture of smooth consistency: each granule of sugar is coated with cocoa butter in such a manner that the greasiness of the product is eliminated and the storage properties enhanced. The tannins are apparently oxidized by the combination of heat and air to produce a compound of less harsh taste, while the volatile fermentation products, especially acids, are driven off by heat and the constant motion of the chocolate in the machine.

There is probably no other mixing machine in the food industry which has so great an effect upon the quality of the product as the conche machine does on the quality of chocolate. As a result of its importance the machine has been subjected to much study. Numerous improvements, revision in design and additions have been made, but the basic design remains unaltered. The movement of the chocolate during conching is the important feature and this one feature governs the size of the machine. Smaller units generally produce better results.

Longitudinal Conche.—Conches are constructed in two distinct types, the longitudinal and the rotary. The former is preferred because of its efficiency in producing a continuous motion of the chocolate; but it does have a disadvantage in that it requires a fairly large floor space. The longitudinal conche consists mainly of two pairs of pots in which one or more steel or granite rollers are forced to and fro through the pot by means of a plunger arm. The whole mechanism is driven from a central gear. In some types a rake shaped to the ends of the pot is attached to the end of the roll so that the entire mass is moved on each stroke, thus eliminating any "blind" spots in the pot. The pot itself is constructed of steel or in some cases of granite, and is heated by steam or gas. The movement of the chocolate depends not only upon the angle of curvature of the end plates of the pot but also upon the consistency of the mix. These two factors must be so balanced that, as the plunger rolls to and fro, the chocolate will hit the curved end plate and be thrown over the rollers. In other words, the chocolate in front of the roller is thrown to the back of it and, when the direction is reversed, the chocolate back of the roller is thrown to the front, giving a figure-eight motion to the mix. The chocolate is thus given a more uniform heating and is exposed to more air so that the mass is evenly and thoroughly mixed.

Rotary Conche.—The rotary conche also functions as a mill, melangeur, and a medium-grade refiner, and is therefore suitable for use in the mass production of average-grade products or for small manufacturers. Its advantage lies in the economical use of floor space and power. It can, however, be employed as an accessory to the longitudinal conche, whereby the conching time may be reduced up to 50%. The rotary machine consists of a water- or steam-jacketed hemispherical kettle mounted

on a cast-iron base. Just inside the top of the kettle is mounted a wide vertical, perforated, and scored ring serving as a grinding plate. Inside the ring and revolved on a vertical shaft is a rotor which carries swiveled grinding shoes riding on the ring at a pressure proportional to the centrifugal force generated by the speed of the rotor. The chocolate is forced, by means of a central worm, downward and up behind the ring past the heat source where it is heated. The warmed chocolate is then forced through the perforations, where it is caught by the grinding shoes rotating against the ring and spread out in a thin film. The larger particles are ground and thus refined and then fall to the center of the machine so that all of the chocolate makes a complete circuit every two hours. During each complete circuit every portion of the chocolate is spread out into a thin film, exposed to the air to permit volatilization of the fermentation products and oxidation.

(b) *Melangeurs*

These machines are roller mills used for grinding and mixing operations in the preparation of chocolate. The usual design consists of two large granite rolls suspended upon an overcarriage and riding on a rotating steel or granite bed which is heated by a steam coil. Various scrapers guide the materials continually below these rolls. In some types, the rolls are fitted with suitable elevating devices allowing for crushing the materials in the first stages followed by gradual lowering of the rolls as the particle size is reduced. After the mixing is complete the machine is emptied by driving one of the rollers which picks up the mix. The mix is then removed from the roller, by means of a simple scraper, to a chute for further processing.

Ordinary edge runner mixers and disintegrators using steel rollers and steel beds are used throughout the food industry, and resemble the melangeurs not only in construction and operation but also in results obtained.

(c) *Cream Beaters*

Cream beaters are utilized by the candy, baking, and similar industries to produce a more rapid crystallization of sugar so that smaller crystals and a smoother cream will result. The creaming effect is effected by a rapid and efficient agitation of the supersaturated cooled sirup. Usually the cream beater consists of 2 or 4 water-cooled cylinders, each of which contains an efficient beater. The supersaturated sirup is fed in at one end of the cylinder, and is moved through it by the action of the beaters, which cream the sirup at the same time. The creamed sirup or fondant is discharged from the end opposite to the point of entry through an adjustable slide which controls the rate of flow through the machine.

The rapid crystallization of the sugar mixtures liberates considerable heat, the amount of which approaches the heat of solution of sucrose. In order to produce a fondant of excellent quality it is necessary to dissipate the heat rapidly. If the heat is not removed rapidly the fondant will be discharged at too high a temperature and will still contain some mother liquor, which will crystallize in large crystals on further cooling and give rise to a rough or sandy product.

The sirup must be kept in the beater sufficiently long to insure complete crystallization, even though the sirup is completely cooled. The rate of flow through the cylinder is controlled by the slide valve exit which should not be opened until the cream reaches the desired consistency; but once this point is reached the machine will run continuously. It is, however, often necessary to feed some finished fondant into the machine when starting it in order to have it serve as seed for starting the crystallization. The two-cylinder machine permits more vigorous control of these factors and is preferred to the four-cylinder machine from the standpoint of quality control.

A still more efficient beater, which removes the heat more rapidly with a less drastic whipping of the sirup and which produces a fine, even-textured fondant cream, is known as the air-cooled cream beater. It consists of a water-jacketed, copper-lined revolving pan which is agitated by specially designed scrapers and beaters adjusted very close to the pan surface. The sirup is poured into the pan and cooled, after which the machine is started to stir and beat the sirup efficiently.

(d) *Homogenizers*

Milk, mayonnaise, and similar products may experience a separation of the fat so that the quality is impaired. Homogenizing is employed to reduce the size of the fat globule to such a point that there is no tendency for the fat to rise. Homogenizers operate essentially by pumping the product against a steel plate through very small openings of 0.0001 inch diameter at a pressure of about 3500 pounds per square inch. The fat globules, distorted in passing through these small tubes, are sprayed from the openings in a reduced size. Further division results when the globules hit the steel plate. See page 208.

(e) *Marshmallow Beaters*

This type of machine, usually constructed of copper, consists of a jacketed cylinder mounted upon a cast-iron stand. The jacket is connected to water and steam through a suitable control system so that the temperature may be accurately controlled throughout the beating. The top of the cylinder is closed by means of a specially constructed lid through which various ingredients may be added throughout the mixing period without shutting the machine down. This lid is also fitted with suitable means for permitting the introduction of cold air and the removal of warm air. The product is discharged from the cylinder through a gate valve at the base of the cylinder. The most important part of this mixer is the double set of vertical beaters, one being fixed and the other rotating at about 150 revolutions per minute. The fixed beaters are arranged at very definite intervals but at variable angles, while the rotating beaters are attached to a frame to move in one plane and scrape the sides of the cylinder. The construction of the beaters is such that a maximum aeration of the product is effected by a continuous beating of air into the mix. Similar mixers, without the covers (that is, open kettles) are used generally throughout the food industry.

(f) Vertical Mixers

These mixers are essentially steam pans fitted with special stirrers in such a way that the batch may be stirred, heated, and mixed continuously while cooking. The stirrer designs are numerous and the shapes many, but all are constructed so the sides of the pan are scraped during the operation, avoiding overheating of the product. Sometimes multiple stirrers operating in opposite directions are used. Variable speed stirrers are also available. In many cases the stirrers may be removed or elevated to any desired position in the pan. Vertical mixers are heavily built and are available in varying designs suitable for performing any kind of mixing and for producing the particular action of mixing and beating that each product may require.

5. Coating and Forming

(a) Dragée Pans

The simple sugar coating of nuts, hard candies, seeds, and the like is generally carried out in dragée pans. The pans, usually constructed of copper or glass-lined steel, are mounted on a stand at an angle of about 60° from the horizontal axis. The pan is rotated at a slow speed and heated by means of a steam coil fitted around the outside. The type and speed of rotation depend upon the nature of the product to be coated.

The principle of dragée work is the deposition of sugar from a supersaturated solution upon the surface of the goods to be coated. The product to be coated is placed in the pan, which is then set in motion, and the supersaturated sugar sirup containing the required flavoring is poured in slowly in small quantities from a dropping funnel or ladle. Only sufficient sirup is added at one time to moisten the product. The pan is rotated until the moisture evaporates, leaving a thin layer of sugar. When this is quite dry, another portion of sirup is added, and the operation continued until the desired coating is obtained. After coating is completed, the product is rotated in the pan until the surface becomes polished. If the product is to be colored, the sirup used for the final coating is colored prior to its addition.

It is essential that each coating be dry before adding another small quantity of sirup; otherwise a spotty product will result. The process can, however, be speeded up by blowing warm, filtered air into the rotating pan to facilitate evaporation of the moisture.

In coating raisins, nuts, etc., the polishing of the chocolate coat presents some difficulties since, under the conditions delineated above, the surface becomes scratched. Glazes, such as gums, are not satisfactory because they impart an unnatural gloss or polish to the chocolate. A simpler method, effecting a more natural gloss, consists of lining the pan with beeswax and allowing the product to polish by slow rotation.

(b) Mongui Machines

Fondant, gum mixtures, and similar products which become semifluid on warming can be poured into impressions made in starch. They reset on cooling; and the starch

can be brushed or blown away, leaving a product having the same size and shape as the impression in the starch. The operation of the Mongul machine is continuous: it fills with starch and levels uniformly sized boards into which it imprints the desired impressions; these are then filled with candy according to a predetermined plan; after cooling, the machine empties the boards and cleans the starch from the candy, which is then deposited into trays or onto an endless belt conveyor. The starch is returned to the system, as follows: The empty trays pass under a screen onto which starch is fed by a bucket elevator from a bin below the machine; the excess screened starch is scraped from the board and the surface carefully smoothed, after which the tray of starch passes under a printing mechanism whose moulds make the desired impressions in the starch; the tray with the impressions passes to the depositor where the candy is cast into the imprints, then travels to an extension of the depositor where it is stacked until the candy has set; after setting, the trays are automatically conveyed from the bottom onto a chain conveyor which transports them to the dumping mechanism, where they are turned completely over and the candy and starch separated by means of coarse screens; the excess starch is removed from the candy by the brushes of the lower concave sieve and a floating adjustable air brush. The cleaned candy is then delivered by the belt conveyor to a receptacle at the side of the machine. The printing mechanism is so synchronized with the depositor that the impressions momentarily come to rest under each jet of the depositor, where the plungers eject a definite quantity of the semiliquid candy from the steam-jacketed hopper. The operation is so carefully controlled that tailing and misshapen pieces are avoided.

The starch used must be clean and dry for efficient operation of the Mongul machine. The moisture content should be kept at about 4%—it must be remembered that the starch absorbs moisture from the fondant as well as from the air. Furthermore, small pieces of candy constantly find their way into the starch and must be removed by screening to avoid a disfigured product.

The consistency and temperature of the candy prior to forming are of great importance in obtaining a clean-cut discharge and a firm set. If too cold or too thick, it will tend to set as it is discharged by the plunger and thereby produce misshapes and tailing. On the other hand, if it is too hot or too thin, the candy will have a tendency to set too hard or have a tendency to grain. In the case of fondant to be covered with chocolate, the temperature should be kept at around 145° F., but for uncovered fondant it should be higher and for marshmallows much lower.

(c) *Enrobers*

Chocolates, cakes, and other products were originally coated by hand dipping, a practice still carried out by smaller manufacturers. Although hand-dipping gives very good results, labor costs are high, each piece being handled individually, dropped into molten chocolate at about 84 to 87.5° F., immersed, and after removal placed on a plaque to set. The first designs of automatic enrobers gave good results at considerably lower costs but the resulting coating was inferior to the hand-dipped

product. The many additions to and variations of the original design have resulted in a machine which gives results comparable to those obtained by hand dipping.

The main differences between the various enrobing machines lie in the construction of the chocolate tanks. In one type it consists of a water-jacketed tank equipped with a paddle stirrer; the chocolate is conveyed to the upper part of the machine by a series of rotating drums, from which it is scraped off into a trough; this trough is fitted with two slits whose width is controlled by adjustable slides and through which the chocolate runs as a curtain. In this type of machine the entire apparatus must be cleaned in changing from one kind of mix to another. A better model has interchangeable units similar to the above except that the molten chocolate is conveyed to the upper part of the machine by a screw conveyor.

The enrober machine is complicated. The centers are fed onto a traveling band and lined up in rows either by hand or by a special attachment. Then they travel over a bottoming mechanism which consists of a small tank of molten chocolate fitted with a rotating drum over which rides a wire belt. The rotation of the drum maintains a shallow layer of chocolate at the surface over which the centers are carried by the wire belt. During this operation the bottoms of the centers are coated with a thin layer of chocolate. The partially coated centers then travel to a canvas belt which rides over a table cooled by water so that the chocolate will set by the time the operation is completed. Too vigorous cooling must be avoided because the centers may become too cold for good covering. From the cooling table the pieces pass through the enrober, where a double curtain of chocolate flows over the centers, covering them completely. The excess chocolate is removed by blowing with hot air while the belt is being vibrated or tapped. This latter treatment removes the excess chocolate and all air bubbles. After this treatment the coated pieces are conveyed by an endless belt to suitable cooling machinery where the chocolate is set.

Control of these operations is essential. Although in some cases the control is left to the judgment of the operator, automatic controls have been designed. Probably the best control consists of three thermostats, one directly in the curtain of chocolate, the other two in the tank, one of which is set at the high, and the other at the low, limit. All are connected to special direct- and reverse-acting air regulators controlling the water and steam valves to the tank jacket. The high-low controls condition the chocolate by continuously cooling portions of the chocolate, mixing it with the bulk, and warming it up again, as well as mixing various proportions of the cooled chocolate with the warmed chocolate in the trough before passing through the slits. Such elaborate control has the following functions:

1. Temperature control as the chocolate flows over the product.
2. Automatically keeping the bulk of chocolates at an ideal covering condition.
3. Preventing undue thickening of the chocolate by high-low controls.
4. Improving the permanent gloss and the lessening likelihood of bloom.
5. Reducing the skilled labor required for hand control.
6. Saving refrigeration because the chocolate sets more rapidly and evenly.

Pieces may be half-coated by passage through the bottoming mechanism at a pre-determined depth. Usually the chocolate is diverted from the trough and allowed to flood the wire belt. An adjustable roller prevents the pieces from floating and thus immerses them to the required depth.

(d) *Antitailing Devices*

As the chocolate covered pieces are transferred from the wire to the canvas belts, a small amount of molten chocolate adheres to the wire and is drawn out in the form of a tail. These tails disfigure the finished piece, interfere with wrapping, and make packing difficult. They may be eliminated by suitable treatment, usually by equipping the enrobers with antitailing devices.

One antitailing device consists of a thin wire moving at high speed just below and in the space between the wire and canvas belts. As the chocolate piece travels from the wire to the canvas belt, it passes over the rapidly moving wire; as the tail sags, the wire cuts it off and removes it.

Antitailing can be effectively carried out by careful manipulation of the size of the gap and the relative levels of the wire and canvas belts. By having the canvas belt slightly lower than the wire belt and at a slight angle, the covered piece leaves the wire belt with a falling motion. This has the effect of making the portion of molten chocolate adhere to the end of the chocolate piece, thus preventing it from being drawn out to a tail. Care must be taken that the difference in level between the wire and canvas belt is not too great, or the chocolate piece will have a very thin covering or no covering at all at the place where the piece first touches the canvas belt. Since the chocolate is still quite liquid at this point, it can be brushed from the candy piece easily if the treatment is too severe.

6. Degassing

Many food products which are not canned are given a deaeration treatment either to improve the color, flavor, or aroma retention, or to reduce the volume of the finished product. Such treatment gives almost complete removal of both dissolved and occluded gases, eliminates air bubbles, reduces excessive foaming, and yields a product which retains maximum freshness and flavor for longer periods of time. The technique involved is similar to that used in exhausting (see page 58).

Powdered products are evacuated and an inert gas allowed to take the place of the evacuated air. Although this procedure is repeated several times, all the air is not removed; the keeping power, however, is greatly enhanced. This treatment has been used to a limited extent with such products as powdered milk and powdered fruit juices.

Chapter II

UNIT OPERATIONS AND PROCESSES (PART II)

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III. PROCESSING (*Continued*)

1. Heat Treatment

(a) *Theoretical*

Automatic Control.—Automatic control is becoming the rule rather than the exception in bringing cookers up to the required temperature, in maintaining this temperature for a specified time period, in introducing the cooling water and air under definite pressure, in maintaining the cooling for a definite period of time, in discharge of cooling water, and in cutting off air pressure. Cookers are usually equipped with a variety of alternative and partially manually operated controls to permit variations in processing. Automatic control has many advantages: It eliminates all uncertainty in the pack, eliminates variations due to processing within the same brand, prevents hot canned products being stacked for various times awaiting their turn to be cooked, permits higher cooking temperatures to be employed, requires shorter cooking times, increases the output per machine, permits close control within very narrow limits, effects a definite saving in the steam consumption, and is easily adjusted to any can size or to any product.

In steam cookers it is important to vent the pocket surrounding the bulb thermometer so that live steam will flow around the bulb in order that it may respond to the true cooker temperature. The location of the thermometer is important, for if it is located near the bottom, which comes to temperature before the top, the steam may be cut off before the top cans reach cooking temperature, and if it is located at the top, then the bottom may be overcooked. It is customary to locate the thermometer bulb in a pocket in the wall of the cooker midway between the top and bottom. In hot water cookers, the thermometer well cannot be vented because of forced circulation of the water. The temperature is usually obtained by connecting the thermometer pocket with a small steam siphon. Some States require recording thermometer equipment on the cookers. The charts and cooks must be identified by some means so that, if spoilage occurs, the lot may be segregated. Cooking records aid in determining the cause.

Automatic controls are usually of two general types, self-actuated controllers and indirect controllers. The self-actuated kind do not give very close control and are therefore not suitable for use on cookers. They are, however, suitable for use on exhaust boxes and other equipment for which closely controlled temperature is not essential. One form consists of a metallic bar fixed at one end and attached to a lever arm at the other: As the arm expands with a rise in temperature it forces a steam valve to close the steam line; as the temperature drops the bar contracts to open the steam valve.

The indirectly controlled types are mostly vapor tension-air control devices. The temperature measuring element is a metallic bulb half filled with a low boiling liquid such as ethyl ether. The bulb is connected by a small metallic tube to a helical metal coil, the free end of which is attached to a pen arm fitted with an ink-filled stylus resting on a circular chart. The volatile liquid gives off vapor in proportion to the temperature of the cooker and is not subject to the lag characteristic of liquid-filled systems. This vapor causes a corresponding rise or fall in pressure within the bulb, connecting tube, and helical coil. The coil expands or contracts, moving the pen arm and stylus across the chart, which is rotated slowly by a clock mechanism giving a complete record of heating, holding, and cooling of the charge. The pressure in the bulb actuates the mechanism controlling the temperature, usually by means of an air-controlled steam valve. The air is admitted from a reservoir through a pressure regulator set at about 20 pounds' pressure. The small tube carrying compressed air is closed when the operating temperature is attained. As the temperature drops, the vapor pressure in the control bulb drops and the helical coil in the instrument contracts, opening a flapper valve situated over the orifice in the air line, thereby allowing the air pressure to operate the steam valve in the main line to the cooker. As the temperature rises, the vapor pressure increases in the bulb and the expansion of the helical coil closes the flapper valve of the air control system, thus closing the air line to the steam valve, which is closed by powerful spring.

The mechanism varies with different manufacturers but all make use of compressed air. Some use it to open the steam valve (direct action), a design which is more desirable, since the valve remains closed if the control systems fail to operate. Some use it to close the steam valve (reverse action); but this is less desirable because, if the control system fails, the valve remains open and may cause the pressure to rise to the bursting point.

Electrically operated temperature regulators are becoming increasingly more popular. A vapor tension bulb is used and a helical coil opens or closes an electrical circuit. The relay then operates a solenoid or motor regulating the steam valve. This type of controller is very sensitive, accurate, and dependable, except during a power failure, and may operate lights on a central control panel also.

Heat Transfer.—By its name, heat transfer means the transferring of heat from the bath to the product being heated. This may be accomplished in two ways, by conduction or by convection.

Heat transfer by conduction is carried out by transferring heat from molecule to

molecule, and is naturally a slow process; it is generally associated with containers, solid packs, or pasty products. Heating a firm gelatin or starch gel illustrates transfer by conduction.

Heat transfer by convection is accomplished by the actual movement of the liquid atmosphere surrounding the product being heated. When the liquid is heated, that portion which is warmer becomes less dense and rises, creating currents which distribute the heat throughout the product. Convection is the more rapid of the two methods of heat transfer. Heating of water, dilute sugar, or brine solutions will illustrate transfer by convection.

There are few cases in the food industry in which both methods of heat transfer do not apply. Some are heated mainly by conduction and some principally by convection, differing in the proportion of each method used rather than in the method itself.

Rate of Heat Transfer.—The rate of heat transfer is determined by measuring the length of time necessary for the center of a pack to reach the temperature of the processing bath or the desired temperature. As may be expected, the center of the pack is always at the lowest temperature, and all processing times and temperatures are determined by the temperature reached at the center.

The rate of heat transfer is governed by a number of factors: temperature differential; method of heat transfer; nature of the pack; degree of disintegration of the pack; size of the container; nature of the container; agitation during heating; and is varied according to the nature of the organisms present. When time in minutes is plotted *vs.* logarithm of temperature at the center of the can, a practically straight line is obtained except for the lag period at the beginning. This indicates that the curve of the rate of heat transfer possesses a logarithmic property.

Time-Temperature Curves.—These curves are a graphical representation of the most important part of heat processing, for merely attaining a temperature sufficient to destroy microorganisms is not enough. A product must be held at that temperature sufficiently long to complete the destruction of the organism itself.

The first step is setting up a heat penetration curve for the product in question. The temperature at the center of the pack is measured at successive intervals of time and the results plotted on graph paper, the temperature on one axis, the time on the other, and a curve drawn connecting the points. Three distinct portions of the curve are observed. The first portion, or rapid rise, is that in which the temperature differential is large and the pack is absorbing nearly all the heat reaching it. The second portion, or slow rise, is that in which the temperature gradient is considerably lower; since the cooker temperature remains steady, the pack temperature rises slowly. The third or flat portion is that in which the cooker heat has been shut off and the pack begins to cool. In the center of the pack, the temperature continues to rise somewhat and then begins to fall. From such a curve the temperature at the center of the can may be determined at any particular time, for the rate of heat penetration is graphically shown. It is thus possible to ascertain the proper time for

processing at any given temperature, provided a knowledge of the organisms present is available.

The rate of temperature change at the center of the pack is not so rapid or so marked as the changes in temperature in the cooker. At the beginning of processing, the container absorbs the first heat applied and passes it gradually into the center, where the temperature rises slowly but steadily. After the cooker has been steadied, the heat continues to be transferred into the center at a still steady but slower rate. After the steam has been shut off and the cooker is cooling, the temperature at the center may continue to rise because it is still at a temperature somewhat lower than the outside of the pack. Meanwhile, the container continues to cool until an equilibrium is reached, when the process reverses itself and the heat passes from the center to the outer portions.

Until a rather recent date, time-temperature relationships were determined by a hit-and-miss procedure. It is now known that the thermal death time of an organism is not a specific temperature but depends upon a time-temperature relationship. As the temperature increases, the sterilization effect is rapidly increased. It is about 100 times faster at 250° F. than at 212° F. Many scientific data are accumulating which, when coupled with practical verification, take the guesswork out of canning. For example, the organism, *Clostridium botulinum*, is responsible for a certain type of spoilage. Its life cycle has been studied, as well as its death time at various temperatures in media similar to that of the product under consideration. The data have been plotted as a thermal death time curve.

Thermal death time curves can be coordinated mathematically with the rate of heat penetration at various cooking temperatures and the rate of cooling under various conditions. Even so, the theoretical time-temperature cooking conditions have certain limitations:

1. The operating conditions may be at variance with the experimental conditions.
2. The consistency of the liquid phase of the cook may be different.
3. The rate of rise of cooker temperature to that required for cooking may vary.
4. The cooking temperatures of the larger cookers may not be uniform.
5. The temperature may vary throughout the cooker.
6. The rate of cooking may vary in the larger cooks.
7. Heat-resistant organisms other than those tested may be present.

Theoretical time-temperature cooking conditions should be tested practically, with no less than 1000 packs; even then, if indicative of correct conditions, a safety factor should be applied to compensate for uncontrollable circumstances.

Influence of Materials.—Containers consist principally of glass and tin plate, the latter conducting heat about 30 times more rapidly than the former. Packaging food in plastics is not yet extensively practiced, but undoubtedly plastics will eventually enter into this picture too.

Water is a very poor conductor of heat when convection is prevented, being only about 25% as rapid as glass. This explains why some foods containing large amounts of water heat slowly. Since the water in these instances is not free to circulate, it must be heated by conduction only. In case heat transference is by conduction the rate will be slow and the composition of the container will have little effect: it has been demonstrated that there is little difference between the heating times of meats potted in tin and in glass; pumpkin, potatoes, sliced apples, and spinach are examples of other food products falling into this category. If the water in the pack is free to circulate, the heat will be transferred by convection and heat penetration will occur as rapidly as is permitted by the container. In such cases, the rate of heat penetration depends on the material from which the container is made. To peas or beans surrounded by free-flowing liquid, heat is transferred by convection, and the rate of the transfer is governed by the composition of the container. Glass containers of the same capacity will take longer than tin plate. Often glass takes twice as long, depending upon the contents. Thus olives in tin reach a cooking temperature in about 10 minutes, but require about 20 minutes in glass. The diffusivity constant (rate of heat conductance) for water is 0.084, for glass 0.37, and for iron 10.8, which means that tin plate transfers heat by conductance about 120 times faster than water.

Influence of Container Size.—Large cans must be heated for a longer time than small cans because there is a greater amount of material to be heated, a greater distance from the container to the center of the pack; and a smaller ratio of surface area to the quantity of material to be heated. The ratio of surface to volume in a No. 1 can is 3.9, and in a No. 10 can, 1.6.

In many cases it is possible to calculate the cooking time of larger cans if the cooking time for the smaller can is known. Unfortunately the following example applies only to those cans whose lengths are greater than their diameters and to packs such as spinach, baked beans, tomato puree, potted meats, and similar products which are heated by conduction only.

If a foodstuff requires 40 minutes to bring the center of the pack up to temperature in a No. 1 can, how long will it take to bring the center of a No. $2\frac{1}{2}$ can up to temperature?

Can Size	Diameter of Can	Diameter Squared
1	.2.7 inches.....	7.3
$2\frac{1}{2}$	.4.06 inches.....	16.5

The time of heating will be in proportion to the diameters squared or $(16.5 \div 7.3) \times 40$ min. = approximately 90 minutes required for a No. $2\frac{1}{2}$ can of the same product.

Influence of Composition of the Liquid Phase.—The liquid phase of the pack has a decided effect upon rate of heat penetration. Salt, sugar, and other crystalloids do not greatly affect the rate of heat penetration except that the viscosity produced in these solutions may retard convection currents. Concentrated sugar solutions and sirups may, because of their viscosity, retard the rate of heat penet-

tration to as low as 25% of the rate of penetration in water. Dilute solutions of gelatin or starch greatly interfere with the rate of heat penetration even when present in very dilute solution. Heat penetration in the case of fresh peas in dilute brine is rapid; but dried or soaked peas give up some of their starch to the dilute brine soon after cooking begins, so the original salt solution becomes a dilute starch solution and the heat penetration rate is slowed up considerably. The same condition prevails for new potatoes, especially if slightly abraded during the cleaning operation, the rate of penetration being retarded in proportion to the concentration of starch in solution. The retarding action of starch increases up to 6%, but above 6% is about the same as that of a 6% solution. The rate of heat transfer for a 6% starch solution is similar to that of pure water without convection currents.

Influence of Size and Nature of the Pack.—Overripe fruit tends to soften and form a compact mass which impedes convection currents, making sterilization difficult. Close packing of the product, and diced or sliced products, behave similarly. In an experiment on the effect of close packing of spinach it was found that a No. 3 can containing 18 ounces required 6 minutes to reach the cooker temperature of 220° F. If 27 ounces were packed in the same size can, it required 46 minutes to reach 220°.

Contamination from microorganisms in the product increases the difficulty of sterilization. Even if the sterilization is accomplished, the mere presence of moldy or otherwise decomposing raw material in the product prior to sterilization greatly diminishes the quality of pack. Sterilization of dry bulk products is extremely slow and ineffective: for example, sacks of cacao beans stacked in a hot room at 150° F. reach a center temperature of 110° in 4 days and 140° after 8 days.

Influence of Rotation.—In practical operation, agitating cookers are much more effective than cookers in which the cans are not agitated. The rate of heat penetration is increased because the agitation or rotation mixes the contents somewhat and

TABLE 2
RELATION OF CANNED CORN ROTATION TO COOKING TEMPERATURE

Can rotations per minute	Time to reach cooking temperature
0.....	90 minutes
10.....	70 minutes
26.....	50 minutes
66.....	15 minutes
110.....	10 minutes

sets up currents within the can. The discontinuous agitating cooker used in sterilizing milk necessarily agitates the milk to prevent scorching of the contents. Most open cookers are of the agitating type, rotating at approximately 11 revolutions per minute. They are especially satisfactory for products consisting of large pieces which fall through the liquid and set up currents. Products of smaller size, like peas and

corn, must be rotated more rapidly, as is illustrated by corn in Table 2. Rotation of the can permits a higher cooking temperature for corn and similar products, especially those heated by conduction.

While this type of equipment is expensive, the results obtained by its use justify the additional expense: the cooking time is shortened, the cooking technique is simplified; and, most important of all, an improved flavor is obtained. From the standpoint of quality control, improved flavor is of prime importance, for an increasing number of consumers consider the flavor of the product rather than the cost price.

Effect of Cooker Temperature.—The higher the cooker temperature, the more rapid the heat penetration because of the greater temperature gradient between the cooker and the can. However, the time required for the can to reach the cooker temperature is the same for all cooker temperatures. A predetermined cooking temperature will be reached more rapidly if the cooker is above this temperature.

Effect of Cooling on Sterilization.—The rate of cooling after cooking affects the cooking of the product. A rapid cooling necessitates a longer cooking, since a slow cooling of the product permits it to maintain a cooking temperature for a longer period of time.

Cooling after cooking is theoretically governed by the same laws as the cooking itself, because the same modes of heat transfer operate, although in reverse. Practically, however, the rate of heat loss is somewhat less because the viscosity of the sirup increases as the product cools and impedes the heat transfer. The dissolution of starch during cooking likewise impedes heat transfer.

Air cooling is slower than water cooling because of the lower heat bearing capacity of air.

Effect of the Heating Medium.—Some processors prefer steam and others, hot water, as a heating medium. However, cans in live steam are soon covered by a film of hot water which conducts the heat from the steam to the can with no greater efficiency than hot water. Experimentally, it has been demonstrated that both are equally effective provided the source of steam is adequate. It must be remembered that the presence of air in the steam greatly reduces the heating value of the steam; so the cooker should be "blown" while coming up to temperature to remove as much of the air as possible.

Effect of the Hydrogen-Ion Concentration.—Acid products are much more easily sterilized than nonacid products. This is the most significant factor affecting canning operations. The apparent or titratable acidity is not a reliable measure of acidity; only the hydrogen-ion concentration can be used as a criterion. This may be illustrated by the fact that plums or apricots may be sterilized in 10 minutes at 167° F., whereas peas and string beans require 4 hours at 212°. The former have a high hydrogen-ion concentration and the latter, a low one. Peas, string beans, corn and fish inoculated with spores of *Clostridium botulinum* and with the liquid phase acidified with lemon juice to 0.2% acidity (as citric acid) are sterilized perfectly in 1 hour at 212° F. However, if not acidified, they are not sterilized even after 3 hours' heating.

A *pH* of 4.5 has been established as the dividing line between the relatively acid and nonacid foods. For the *pH* values of common food, see Volume I, page 28.

(b) *Preheating or Blanching*

All vegetables and a few fruits must be blanched to destroy those enzyme systems which might adversely affect the quality of the product during the relatively slow rise to cooking temperature. Blanching also acts as a cleansing operation in that it removes traces of foreign matter which may impart disagreeable flavors. It does not materially reduce the thermal death time of resistant, spore-bearing organisms, as is generally believed, but principally benefits the product by removing some of the microorganisms.

TABLE 3
PREHEATING PERIODS AND TEMPERATURES FOR TYPICAL FOODS

Product	Time, min.	Temperature, ° F.
Apples	5	180-190
	3-4	212
Asparagus	2-4	212 ^a
Beans (green)	2-10	212
Beets	10	220
Brussels sprouts	3-5	212
Carrots	10-15	212
Celery	3-4	212 ^b
Figs	10	212
Mushrooms	10	212
Peaches	1-2	175 ^c
Oranges	Several	175-185
Sweet potatoes	9-12	240

^a Removes bitter mucous-like material.

^b Citric acid blanch.

^c Inactivates oxidase to 1-2 millimeters below surface. Ten minutes required to inactivate it in entire peach half.

Blanching is usually carried out immediately following preliminary preparation and usually just prior to filling the cans. Many plants carry out the blanching process directly in the can, the cans then being tipped and drained before filling with salt or sugar solution. This latter procedure is used to a considerable extent in the United States, but has not found favor among European processors.

Blanching is usually a preliminary heating in boiling water, the time of heating varying with the product. The hardness of the water used has a decided influence upon variation in product quality. In the immersion method, the first batches of the product remove most of the calcium and magnesium salts from the hard blanching water. Later batches will be subject to contamination from the used blanching water, especially by thermophilic bacteria and by off-flavors. In the immersion process, therefore, the blanching water must be replaced continuously in order to avoid harmful contamination of succeeding batches.

Although blanching or preheating periods and temperatures used vary with the

manufacture for any given product, the approximate blanching data for some typical products may be listed (Table 3).

There appears to be no well-established technique for blanching. Although the modifications employed are almost as numerous as in canning factories, two methods seem to be in general use:

1. *The Batch Method.*—This immersion method is perhaps the simplest known method for blanching. The vegetables to be preheated are placed in wire or perforated baskets and lowered into boiling water for a predetermined period of time.

2. *The Continuous Method.*—In large factories, the blanching process is entirely automatic, the period of blanching being controlled by the speed of a continuous acting, spiral cylinder which is governed by an automatic speed drive. The water overflows where the vegetables enter the machine. The vegetables are constantly being pushed forward into cleaner water. Automatic blanching machines insure uniformity of heat treatment while permitting the operation to be easily varied for different vegetables.

Influence of Initial Temperature.—The temperature of the pack going to the cooker is of great importance in the cooking of products which conduct heat slowly. As may be expected, the time required for the center of the pack to reach the required temperature is greatly influenced by the temperature immediately prior to cooking. In cooking corn at 240° F., the following holds: If corn enters the cooker at 70° it requires 80 minutes, but if it enters the cooker at 160° it requires 40 minutes, to reach the temperature of the cooker. Hot packing or hot exhausting is a very material aid in the cooking processes especially if the product is heated by conduction.

If one set of conditions is known for a poor heat conducting product, its behavior under other conditions can be calculated.

Thus, if one can enters a 240° F. cooker at 184° and reaches 226° in 60 minutes, and a second can of the same size and product enters the same cooker at 90°, the temperature of the second can may be calculated from the temperature differentials of the two and the temperature rise of the second. The temperature differential of the first can is 56° and the second, 150°, so the second can will heat 150/56 times as fast as the first. The first can heated 42° in 60 minutes; therefore the second will heat $150/56 \times 42$, or 112.5°, in the same time. Since it entered the cooker at 90° and increased 112.5° in temperature, its temperature at the end of 60 minutes is $90 + 112.5^\circ$, or 202.5°. These calculations have been verified experimentally.

(c) Clinching

Clinching is the process of loosely curling the cover and the flange on the can.

This operation is used by some food packers between siruping and the exhausting in order that the can may be exhausted at a temperature (200–210° F.) higher than that which may ordinarily be used with open cans. The clinching machine spins the lid loosely onto the can by an action not quite so strong as the first operating roller on the sealing machine. Clinching eliminates damage to the pack by splashing, and also protects the surface layers from the bleaching action of the steam. The air can escape from under the loosely spun end; yet the surface of the pack is not chilled between the exhaust box and the seaming machine, thus permitting a high

effective closing temperature. Clinching also prevents damage by the seaming machine to those fruits which rise excessively during exhausting.

(d) *Exhausting*

While the term is often used to imply the heating of the can and its contents, more correctly it means treatment under vacuum to remove air and other entrapped gases, at least partly, before the cans are sealed. Hot vacuumizing removes gases, especially oxygen, and thus reduces can corrosion, lessens the development of oxidized flavors, and lessens destruction of vitamin C. Most fruits packed in sirup entrain some air during can filling, the amount depending upon the temperature of the contents, as well as the nature of the liquid phase. Higher viscosity in the liquid phase tends to increase the amount of entrained air; a higher temperature tends to lower the viscosity, permitting the escape of this air. Also, dissolved substances in the liquid phase may act as emulsifying agents and impede the removal of the entrained air by their protective colloid action. Considerable quantities of gas, especially carbon dioxide and nitrogen, are dissolved in the fruit tissues. Air is also entrapped in the head space above the contents when the lids are spun on. Clinching facilitates the exclusion of entrapped air.

Exhausting prevents undue strains on the seams of the can during the cooking operation, since cans sealed at lower temperatures develop very high pressures during cooking. The pressure developed during cooking decreases more rapidly than the temperature of sealing increases. Exhausting reduces the mechanical strains on the seams of the cans at the first stage of cooking. Care must be taken, however, to govern the exhausting by the size of the can. Cans such as No. 3 cans or smaller may be exhausted thoroughly and after processing will show a vacuum of 8 to 15 inches, while larger cans may become panelled, with sides drawn in, or they may even collapse. The less head space in the can, the greater the vacuum obtainable in the finished product. Exhausting makes the ends of the cooked and cooled can concave, an indication of a sound condition to the purchaser. Convex ends usually indicate gaseous spoilage.

High sealing temperatures insure a relatively high vacuum after processing and cooling and reduce the rate of formation of hydrogen swells. While exhausting is ordinarily carried out at about 185 to 205° F. (Table 4), a longer exhaust at the lower temperature is preferred to a short exhaust at a high temperature if only the effect produced and not the efficiency of operation is to be considered. Glass containers are usually filled hot and then exhausted thoroughly. Exhausting tends to prevent overfilling of the cans, and permits a greater fill of soft products such as berries.

Vacuum.—It is customary to use a heating process for exhausting although simple vacuumizing also produces somewhat the same results. In one method, most meat and fish products (Table 5) are vacuumized by a vacuum-sealing machine and the lids spun on while the can is still in the evacuated chamber. Another method spins the lids in the ordinary way leaving a small vent hole open; the cans leaving the seal-

ing machine are placed on trays, which are then placed in a well-lighted vacuum chamber having a small window at the top; the chamber door is clamped on and the chamber then evacuated by a pump; while still under vacuum the vent holes are soldered by an electric soldering iron fitted through the top of the evacuated chamber.

Heat and Vacuum.—In fruit canning, exhausting is carried out by means of an exhaust box heated by steam or hot water, the latter being preferred. Steam is likely to cause a softening and slight discoloration of the fruit at the top of the can unless clinching has been applied.

TABLE 4
EXHAUSTING TIMES AND TEMPERATURES FOR TYPICAL FOODS

Product	Time, min.	Temperature, ° F.	Product	Time, min.	Temperature, ° F.
Apples	7	190	Pimentos	12-15	200-212
Apricots	4-8	190-212	Pineapple	4-6	185-204
Asparagus	5	180	Plums	5-6	180-190
Beans (green)	4-6	212	Potatoes	..	180
Blackberries	5-10	180-212	Prunes	4-6	200
Brussels sprouts	6-8	212	Raspberries	5-6	180-190
Cherries	5-10	165-190	Spinach	10-14	212
Currants	5-6	180-190	Strawberries	5-6	180-190
Gooseberries	5-6	180-190	Sweet potatoes	18	185-200
Grapefruit	Long	....	Tomatoes	Long	130-150
Grape juice	20-30	80-100	Crushed fruit	10-12	200-212 ^b
Loganberries	5-6	180-190	Ripe olives	4-5	200-212
Peaches	4-8	190-212 ^a			

^a Ten minutes at 180° is preferred to 4 minutes at 212°.

^b The penetration is slow.

TABLE 5
FOODS EXHAUSTED WITHOUT HEAT

Coffee in cans
Fish and fish products in glass
Preserves in glass
Jellies in glass

TABLE 6
FOODS FOR WHICH EXHAUSTING IS UNNECESSARY

Corn
Peas
Pumpkin
Cider
Asparagus

Chain-Track Type.—One pattern of exhaust box operates in the following manner: The cans are fed in a straight row from the siruper to a revolving disk which places them on a carrier chain; since these disks have a greater speed than the carrier chain, the chain is filled solidly with cans, and carries the cans through the exhaust box which has the bottom part filled with water heated by steam; the chain track inclines gradually from each end so that the lower half of the cans are immersed in hot water while the upper half are heated by means of closed steam coils; the cans pass out of the exhaust box onto another disk which passes them singly to the sealing machine.

Disk Type.—Another type, used in more modern canneries, operates in a somewhat different way. A rectangular metal box is fitted with a series of metal disks 15 to

18 inches in diameter in 3 or 4 rows. These are in turn fitted with intermeshing cog gears. The cans are guided from one disk to the next, through the hot water or steam, by curved iron bars above the disks. They travel down one row of disks and back the next, the length of the box and the number of the disks being varied to suit the capacity of the plant and the nature of the product to be exhausted. This kind of exhaust box is excellent when a moderately long exhaust is required. Another type is similar to the preceding except that steam-heated pipes guide the cans through the box.

Circular Type.—A circular type is useful when floor space is limited, because it utilizes concentric rotating disks. The cans are conveyed to the center by means of a guide and chain, and are deflected to each succeeding disk at the completion of travel. The cans follow a spiral path through the box.

The usual circular type of exhaust box will take all can sizes up to a gallon without any adjustment. It is customarily heated by live steam. The cans make three traverses of the box and are transferred from one conveyor to another automatically. Adjustable speed gears control the time of heating the can and hence the temperature attained by the cans. This kind of exhaust box is well adapted to all classes of products.

Cable Type.—The cable exhaust box is the simplest type, and consists of a narrow, shallow, rectangular metal container. A steel cable passing through the box, carries the cans. A modification replaces the cable with a chain conveyor, the main objection to which seems to be jamming of the cans and the consequent delay and inconvenience.

Rotary Type.—In this exhaust box the cans are carried through a steam-filled cylinder on a reel.

(e) Seaming

Seaming—or, more commonly, double seaming—is the step in which the cans are passed through a machine known as a double seamer. This rolls the curl of the cover and the flange of the can with the gasket or sealing compound into the familiar airtight double seam. See page 346.

The importance of high-temperature closing is generally recognized although the reasons for it are not always understood. An effective closing temperature depends on the actual temperature of the head space gases at the time of closure and varies with the form and nature of the product. High closing temperatures reduce subsequent corrosive action by avoiding chilling of the surface, which reduces the temperature and therefore increases the subsequent content of gases in the head space. An advantage of high-temperature closing of vegetables is preventing the development of excessive pressures during processing. Clinching is an effective method of obtaining high closing temperatures but is, as yet, not universally adopted. Open-ended cans leaving an exhaust box usually exhibit a temperature of 160 to 170° F. at the center of pack and a vacuum of 12 to 15 inches after processing and cooling.

(f) Sealing

Cans, excepting those sealed under mechanical vacuum, should be sealed at not less than 130° F.

(g) Cooking or Sterilization

Cooking is the most important unit operation in the canning industry. It is not sterilization in the strictest sense, for there are present after cooking some heat-resistant aerobes or thermophiles which cannot develop, however, because of unfavorable conditions; sterilization is the complete destruction of all forms of life in the product being processed. Cooking does, in as short a time as possible, render

TABLE 7

COOKING TIME AND TEMPERATURES IN NONAGITATING COOKERS FOR TYPICAL FOODS IN NO. 2 $\frac{1}{2}$ CANS

Product	Time, min.	Temperature, ° F.	Product	Time, min.	Temperature, ° F.
Apples	8-20	212	Okra	17	240
Apricots	4-15	212	Oranges	..	Not above 185
Asparagus	20	240	Peaches	15-40	212
	30	235	Pears	12-25	212
Beans (Lima)	20-45	240-250	Peas	35	240
Beans (green)	30-35	240	Pimentos	30	212
Beans (baked)	60	240	Pineapple	10	212
Beets	25-40	240	Plums	7-14	212
Blackberries	7-9	212	Potatoes	30-45	240
Brussels sprouts	25	240-250	Prunes	20	212
Cabbage	25-40	240-250	Pumpkin	90	250
Carrots	30-35	240	Raspberries	4-12	212
Cauliflower	20-25	240-250	Rhubarb	13	212
Celery	25-30	240	Spinach	50 or more	252
Cherries	12-25	212	Strawberries	5-9	212
Corn	70-90	245-250	Tomatoes	10-15	220
Currents	10-15	212		30-35	212
Figs	110	212	Fruit cocktail	..	210-212
Gooseberries	6-10	212	Crushed fruits	10-20	212
Grapes	12	212	Ripe olives	60	240
Grapefruit	20-30	180-190	Fruit juices	Flash	180-185
Loganberries	6-10	212		20	175
Mushrooms	...	230-235		30	149

the product stable against spoilage by microorganisms. Texture, flavor, and appearance of the product are improved by cooking. Insufficient cooking will permit microbiological destruction of even the finest product, while overcooking reduces high-quality goods to the standards of inferior grades. The cooked product, obviously, should be sealed in such a manner as to exclude all microorganisms. Pressure cooking is a means of destroying heat-resistant organisms quickly.

Cooking temperature and time of cooking vary with the product to be processed (Table 7). Products of low acidity, high protein content, and containing sporegenic microorganisms are very difficult to cook properly. The acidity of fruits,

tomatoes, and rhubarb lowers the thermal death time of contaminating organisms. Fruit juices are always cooked below 212° F., the range of 150 to 185° being used in practice because higher temperatures injure flavor. With the exception of olives, fruits are easily cooked at 212° for the purpose of cooking rather than sterilizing. Vegetables, except those of high acidity, must be heated at 212° F. for 3 to 10 hours to destroy spores. One cooking of meats or vegetables at 212° is unsafe because of the danger of survival of the spores of *Clostridium botulinum*. Intermittent cooking at 212° in three periods of 1 hour each, spaced 24 hours apart, is more effective and safer than a 3-hour continued cooking; but even the intermittent method does not destroy *C. botulinum*. Several meat or vegetable products are acidified to make the cooking process easier. Lemon juice, vinegar, citric or tartaric acid, or some other harmless acid is used. In general, vegetables require a more severe cooking not only because of their low acidity but also because of their hard texture and their proximity to soil contaminants during their growth, especially to spore forming organisms. Since temperatures which would spoil the color, flavor, texture, and appearance of fruits in many cases improve the flavor and texture of vegetables, vegetables are usually cooked at temperatures above 212° F.

The specific heat of most fruits and vegetables is practically the same as that of water; the error is small if it is assumed that the same amount of heat is required as would be needed to heat a similar weight of water in a like package. Altitude does not affect the temperature of steam cookers operating at pressures above atmospheric. The boiling point of water decreases by 1° for each rise of 500 feet in altitude; and it is recommended that an additional cooking time of 2 minutes be employed for each degree below 212° F.

From the time-temperature relationships it is to be concluded that each cooker, regardless of type, should be equipped with: an automatic temperature controller with at least two-thirds of the bulb in the principal cooker chamber, an indicating mercury thermometer, a recording thermometer with a range of 170° to 270° F. in not more than 2° divisions, a pressure gage (preferably a compound type) from 0 to 30 pounds in 1-pound steps, a vent of at least $\frac{3}{4}$ inch in diameter to be used during the coming up period, a $\frac{1}{8}$ -inch bleeder in each thermometer pocket to be opened during cooking, at least one $\frac{1}{8}$ -inch bleeder in the top of the cooker to be opened during cooking, a steam by-pass around the controller to permit a rapid rise in the temperature, a perforated steam line entering the cooker at the bottom beneath a perforated steel plate, and, finally, an adequate drain in the bottom which may also be used as a vent.

In manual operation, pet cocks and drain valves should remain slightly opened and blown throughout processing to insure circulation of the steam in the cooker. This obviously causes the use of an extra amount of steam, as well as excessive depreciation in pet cocks and valves. Thermometers and steam gages should provide the control. Usually, in smaller canneries, the cans are cooled in the cooker.

Three important methods of heating cookers are in general use: the steam method, which is used to the practical exclusion of other methods; the steam plus air method,

which is used mainly for glass containers; and the water plus air method, which is also used mainly for glass containers.

Steam Method.—The steam method consists of bleeding the cooker generously through vent pipes at the top during the first (or coming up) period of operation to remove all the entrapped air which would interfere with uniform heating. After reaching the operating temperature, the thermometer and pressure gages should agree; a higher pressure than is indicated by the temperature indicates entrapped air. After reaching operating temperature, the vents are closed and the bleeders are opened, allowing enough steam to escape to remove noncondensable gases which enter with the steam and to promote circulation. After cans have reached the cooking temperature, they tend to maintain a constant temperature, so the presence of air becomes less objectionable. The most important cause of irregularity in the temperature during the coming up period is the condensation of the steam on the cans at the point of steam entry, since early in the heating period the steam gives up its heat to the relatively cold cans and is thus condensed, leaving much less steam to rise and heat the cans above.

Steam plus Air Method.—The steam plus air method is prohibited in California because of the difficulties in securing uniform heating of the product and in securing rapid heating. Many authorities advise against its use because containers drop below the cooker temperature and recommend instead the water plus air method.

Water plus Air Method.—As stated, the water plus air method is used especially for processing foods in glass containers. The cooker, equipped with an overflow valve and a sight gage to show the water level, is filled with water to well above the top-most jars. The glass containers are protected against bursting because of the excessive pressure attained by expansion of the water or by condensing steam. Steam is then admitted to heat the water, and air is admitted to agitate it and to maintain the additional pressure required to hold the lids of the jars in place. The steam and air should be mixed outside the cooker to heat the air before its entry into the cooker and to minimize rumbling. The mixture is admitted through three tangentially placed muffled jets to give a vigorous rotating motion to the water. This permits additional agitation, rapid and uniform heating, and very little noise and vibration.

This method gives a much more uniform heating of the containers at different levels in the cooker during the coming up period than either of the other two methods. However, it requires more heat to bring the water up to the cooking temperature. It is customary to admit air and steam through a perforated pipe across the bottom of the cooker, which should be well vented.

Continuous Variable Discharge Type.—The continuous variable discharge cooker has been extensively used in the cooking of fruits, most of which can be processed more quickly and uniformly this way than by the open tank method. The cans quickly reach an effective cooking temperature. The duration of cooking is not determined by speed but is governed by which door is opened in a series of small doors along the path of can travel.

The cans enter a small port hole at one end of the cooker and travel along a spiral

path inside the cooker, being rolled continuously during their period within the cooker. The cooker consists of a long metal tank of heavy boiler plate inside which is a spiral extending throughout the length of the cooker held stationary, and secured to the tank by an angle iron. The inner member or cylinder reel revolves slowly, pushing the can along the spiral path, each can being in a separate pocket. All the cans travel a length equal to their height on one revolution of the reel. Modern processors of this type are fitted with a number of inlet and outlet doors near the top, so that the process time may be varied at will.

The cooker is filled about three-fourths full of water for processing the cans under water. If used without water, the cans may be processed in live steam. There are advocates for each method. The water method of operation has one important advantage—it permits operation at any desired temperature. For example, canned fruit juice may be pasteurized at 160° F., the temperature being controlled at 1-2° below the boiling point by automatic means. This control reduces large heat losses, permits closing of the steam line at frequent intervals when cans are not being processed, and permits far less steam to escape into the cook room, thus leading to better working conditions.

The evolution of the continuous variable discharge cooker is interesting. Originally it was rectangular in cross-section, then gradually changed into a cylindrical and circular cross-section. The present trend is to make the lower half of circular cross-section and the upper half rectangular, permitting ready access by a simple lifting of the flat lid. Cans invariably become crushed in the processing and hence may be removed from the cooker more easily than if the lid is cylindrical.

The capacity of the cooker varies with its length and diameter. The length of the cooking period influences the capacity. The maximum output may be found by dividing the number of cans required to fill the reel completely by the length of the processing time in minutes. In actual practice, however, the maximum holding capacity of the cooker is not used, since the length of the process is controlled by the use of port holes for the entry or the emergence of cans at various points along the side of the cooker. The speed of rotation of the reel is seldom varied, and the cooker operation is usually synchronized with prior steps.

Batch Methods.—Formerly, foods, especially meats, were cooked by immersion into calcium chloride baths, a method abandoned since the adoption of pressure cookers.

Pressure Methods.—There are two types of pressure cookers in general use, the horizontal, which is the more popular, and the vertical. Parallel installations of smaller units are more common than larger units because the food has more of a "home cooked" flavor when prepared in smaller units. A $3 \times 3 \times 6$ foot unit is a popular size.

Discontinuous Nonagitating Pressure Cookers.—With these cookers temperatures of 240° F. or higher are easily obtainable. The simplest form consists of the upright or horizontal heavy steel cylinder either of which is heated by steam. The upright cooker, which is sunk to below floor level, is more popular in the East, and the hori-

zontal cooker is more popular in the West. Upright pressure cookers are usually operated in batteries above which is a traveling crane operated by air pressure. Cans are placed into circular crates and lowered into the cookers, which are usually small in size. Since only a small number of cans are required to fill this cooker, the exhausted or sealed cans do not have an opportunity to cool appreciably before cooking.

An advantage claimed for horizontal pressure cookers is that the cans are put in crates or small steel cars which are easily and quickly placed on the steel track in the cooker. Usually both ends are equipped with heavy swinging doors so that the cooker may be fed at one end and discharged at the other. The usual size is 5 feet in diameter and 10 to 20 feet long.

Discontinuous Agitating Pressure Cookers.—This type was developed especially for use by the dairy industry for the sterilization of milk, since milk tends to scorch and curdle unless thoroughly agitated during cooking under pressure. The cans are placed in a cage within the cooker and the cage revolved during cooking so that the cans are constantly in motion. While this type of cooker is not used extensively for other products, it would undoubtedly be of service in the cooking of some vegetables.

Automatic Pressure Cookers.—Several types in this class are now available for the cooking of vegetables and meats.

The *continuous cooker* takes round cans only and consists of a horizontal steel cylinder capable of withstanding the necessary pressure. Inside the cylinder are a reel and spiral similar to that described for the continuous variable discharge type (see page 63). A special valve allows the cans to enter the cooker without the pressure in the latter being affected.

Another type carries the cans on an endless chain. They pass into the cooker through a rotating valve of the "hotel door" type, and are carried through a series of gently sloping stages, that is, they go down one side of the cooker and up the other and emerge from the cooker through a valve of a similar pattern to the entrance valve.

Still another type takes cans of various shapes and sizes. It is easily adjusted with respect to time and temperature of processing and takes up only a small amount of floor space. Its action is smooth but not quite so completely nonagitating as the cooker described above which it resembles. The cans enter the cooker by way of a feed port and a slide valve of special construction. They are then deposited on pallets attached to the chain conveyor. The vertical conveyor is fixed to a horizontal drum rotating on a vertical shaft which passes through the center of the retort. The discharge is effected through a port valve.

For the *continuous agitating pressure cooker*, the principal difficulties which had to be overcome were the admission and removal of the cans from the cooker without releasing the steam pressure. A much higher temperature may be used, permitting a much shorter time of cooking, because the agitation prevents overheating of the product in contact with the container. Agitation, of course, increases the rate of heat penetration; hence a shorter processing time is required. The principal dis-

advantage lies in its high initial cost. This type of cooker is especially effective in the processing of corn and spinach.

Open Cookers.—The term is likely to be confusing for such cookers are almost completely enclosed. "Open cookers" refers to cooking at atmospheric pressure at about 212° F. Up until about 20 years ago, cooking was accomplished in wooden tanks containing boiling water or calcium chloride solutions as the bath. The cans, in crates, were lowered into this bath by means of cranes. The temperature was maintained by open steam jets. The method is still used somewhat by some small canneries and to a limited extent by large canneries for the cooking of small miscellaneous lots of fruit.

(h) *Tempering*

Tempering is the rigid regulation of the cooling temperature in such a manner that the package is not misshapen or broken by too rapid cooling.

It is necessary to temper some products canned in tin plate, especially large cylindrical cans, in order to prevent buckling. Medium and square asparagus packs must be tempered. For glass packs, when the processing period is completed, rapid cooling of the contents is necessary to arrest the cooking. Admission of cold water against the glass containers would break them, and the releasing of the pressure would permit the excessive internal pressure to force the lids from the jars. Therefore, the cooking in glass jars requires a tempering of the ingoing water by means of heating it to a safe temperature with steam. The temperature is gradually lowered with the simultaneous admission of air to maintain sufficient pressure to prevent the loss of the lid. Air rising through the water mixes it and prevents the blanketing or layering of the water in different temperature levels.

(i) *Cooling*

The cooling of cans after processing is not always given sufficient attention because its importance is not always realized. Fruit canning is carried on during the hottest months of the year. If the cans are hot when stacked they retain their heat for a considerable time; rapid cooling and cool storage will aid fruit in retaining a bright and attractive color. Thus, after cooking, it is essential to have the can and its contents cooled immediately. Unfortunately it is customary for many canneries to stack the cans in piles after cooking, the heat retained possibly continuing the cooking for several days, especially in the cans at the center of the stack. This continued cooking results in the development of a dark color in peaches and pears and in the scorching and darkening of tomatoes and other vegetables. Good cooling also aids in curtailing the losses in certain vegetables attributed to flat sour development, a condition caused by the growth of a thermophilic, spore bearing organism which survives the cooking process. Rapid cooling improves the quality of meats by preventing excessive cooking and overcooked texture, prevents further destruction

of the jelly strength, obviates overcooked flavor, and reduces excessive strains on the cans. Rapid cooling and cool storage are also among the important factors preventing the formation of hydrogen swells.

Chlorination of cooling water has been recommended to eliminate contamination arising when the can seams open up somewhat under the stress of sudden cooling. The seams reclose with further cooling, entrapping some bacteria which may become a possible source of contamination. But chlorination of the cooling water may increase rusting of the cans. Chlorination is generally not popular. The use of water with low bacterial count for cooling water is perhaps a better procedure.

Cans should be cooled quickly and as soon as possible after sterilization, but care must be taken not to cool them to too low a temperature because they may remain wet and become rusty. Usually they are cooled to a temperature of 110 to 115° F., which is high enough to dry the cans but not high enough to cause injury to the contents.

Cooling is usually accomplished by one of two methods, spray cooling or immersion cooling, either of which requires large amounts of cold water. Cooling under sprays results in a more efficient use of cooling water because it takes advantage of the large amount of heat absorbed by the evaporation of the water from the can surface. This method is very successful in the cooling of orange juice, when extremely rapid cooling is imperative. The spent cooling water may be recooled by tower and re-used.

Batch Type.—After pressure cooking, cooling is sometimes accomplished by introducing water into the pressure cooker, during which process it is necessary to have a counterbalancing air pressure or a very high water pressure. The maintenance of this pressure by air or water is very important, for the can is likely to burst unless its pressure inside is counterbalanced. During the cooking process, when the cooker is filled with steam, the introduction of cold water would immediately condense the steam, which would cause a sudden drop in the cooker pressure. The net result is a sudden increase in the pressure within the cans. The external pressure drop must be simultaneously counterbalanced by an increase in air pressure or water pressure to maintain a state of pressure equilibrium in the cooker. At the end of the cooking period, the steam is turned off and air introduced until the air pressure is 2 to 3 pounds more than the processing pressure. Cold water is admitted cautiously, and any drop in pressure must be immediately restored by air pressure. Water is gradually added in larger amounts until the cans are covered, while the processing pressure is maintained by means of air. After the cans are covered with cold water, the counterbalancing air is released. The door or lid may be opened, the cans may be removed at this time, and cooling may be continued by some other means. Usually the cooling process is completed by stacking the cans overnight in an open court in such a manner that air currents may pass freely around them.

Continuous Type.—Following continuous variable discharge cooking, an automatic cooler is usually used. The cans are cooled by passage through a machine similar to the cooker. In this case the reel runs through cold water and under water

sprays. Most of the continuous type cookers are fitted with continuous coolers of similar design.

(j) *Pasteurization*

Pasteurization is the subjecting of a product to a temperature which destroys a great many, but not all, of the organisms present. The various yeasts are destroyed by heating for a few minutes at 140 to 150° F. Resistant mold spores require 20 minutes at 175°. Carbonated juices are pasteurized at 150° for 30 minutes; high carbonation does not noticeably affect the thermal death time of typical fruit juice organisms. Juices of high acidity are generally pasteurized at 160 to 165°. The most troublesome enzyme systems are inactivated by pasteurization. There are a number of methods of pasteurization, each of which has certain advantages. This subject is discussed more fully on pages 320 and 623.

Batch Type.—The continuous method of pasteurization consists of passing the liquid through a single metal tube or series of small metal tubes which are heated to the desired temperature by steam or hot water. The tube or tubes are usually made from block tin, aluminum, or silver-lined copper, but stainless steel is generally preferred. Steam heating is somewhat objectionable because it does not permit a very exact regulation of the temperature and is likely to cause scorching or overheating of the product. Hot water heating is generally preferred because it is possible to regulate the temperature exactly at a temperature differential of only 6° F. and there is therefore little danger of overheating the product.

Discontinuous pasteurizers usually are steam-jacketed kettles or tanks equipped with steam coils. The food product is placed in the kettle or tank and heated to a desired temperature for a predetermined length of time. There are a number of outstanding objections to this type of pasteurizer: It is a batch type, exposing the product to air and oxidation and to local overheating and scorching. Prolonged heating also injures the color and flavor of the product.

Electrical Type.—Electrical pasteurization has been suggested many times. In this procedure, the liquid is passed between carbon electrodes where it is heated instantaneously to the desired temperature. Ordinary 110-volt and 60-cycle current is used and permits easy regulation to almost any temperature. The product is not scorched because the electrodes are not hot, the heat being generated by the passage of the current through the liquid.

Flash Type.—Flash pasteurization is one of the newest forms to attain general acceptance. Formerly, this method of pasteurization was not permitted by the boards of health of certain States, but one by one they have withdrawn their objections. The pasteurizer consists of three parts: The first section acts as a preheater, the heating water coming from the third or cooling section; the second section is the pasteurizing section heated by steam or hot water to about 180 to 185° F., the product taking only a few seconds to pass through this section; the third section is the cooling section where the hot product is cooled by cold water. The used cooling water, now

warm or even hot, is then passed to the first section. There are many advantages to this type of pasteurizer: Higher temperatures and correspondingly shorter heating periods are used; the heating time is so short that there is little change in flavor or appearance of the product; the preheating, pasteurization, and cooling are all carried out in one unit in which the product is processed without access to air and oxidation; and by the re-use of the cooling water in the preheater the steam consumption is low.

(k) Roasting

Roasting is usually applied to nuts and beans of various sorts in order to bring about a desired flavor rather than to effect sterilization. Obviously the temperatures of the product during roasting are sufficiently high to destroy enzyme systems, molds, yeasts, and at least a part of the contaminating organisms.

Since roasting is customarily carried out with dry heat, a considerable amount of moisture is removed during this operation. The loss of moisture produces crispness and a desirable flavor in the case of nuts, and a special flavor in the case of coffee and cocoa. Methods of roasting and the results achieved vary with each individual product. See Volume I, page 846.

The types of roasters in use in the food industry are almost as numerous as the products to be roasted. The roasters in general use are heated by hot air or direct heat. Elaborate batch type and continuous roasters are used in large factories. Hot air types using oil-fired heaters are also available.

Hot Air Type.—The most efficient roaster is the hot air type in which the product is fed into a hopper and then passed into a globular-shaped vessel. Air is passed through a gas heater and blown directly upon the product, which is kept in constant motion by rotation of the container. The fumes from the burning dust and fragments of various extraneous materials are removed by the hot air, thus preventing the development of foreign and crude flavors. The machine is capable of being rapidly charged and discharged by simple operation of the slides. The duration of the roast varies with the size of the charge and degree of roasting, usually 30 to 40 minutes for a charge of 300 pounds for a medium roast. The cooler is fitted with air suction to facilitate rapid cooling of the beans. The agitators consist of rotating rakes. The apparatus is equipped with recording thermometers.

Direct Heat Type.—The most common type of direct heat roaster is a gas heated rotating cylinder having a capacity of 100 to 200 pounds and heated by a series of gas jets impinged upon the outer surface of the cylinder. Forced air draft is obtained by a fan fitted onto the machine. The product is placed into a hopper mounted on top of the cylinder and thence into the cylinder by means of a slide. After the cylinder is set in motion, the gas jets are lighted. As the temperature rises, the moisture comes off as steam and escapes from the sides of the roaster. A small hole in the center of the cylinder axis permits insertion of a thermometer and removal of samples during roasting.

Certain disadvantages accompany this type of roaster. If the product is brittle, it is

inclined to break during agitation. If portions of the product are charred, a smoky flavor may be imparted to the product.

2. Heat Removal

THEORETICAL

(a) *Refrigeration*

Refrigerators are, in most cases, the site from which operations in the food industry begin. They may be regarded as a temporary holding house for stocks. More specifically, they may be regarded as general storehouses for any product awaiting storage, examination, cooling, or a convenient time for processing or distribution, especially in the case of meats and meat products. Capacities of such equipment are generally expressed in terms of ton refrigeration. A ton refrigeration is equivalent to the removal of 288,000 B.t.u. per day or 200 B.t.u. per minute.

A refrigerator may be operated successfully by observing certain precautions which, unfortunately, are often not appreciated.

Safe Temperature.—Safe temperature is that temperature above which troublesome bacteria cease to be dormant and become active. A knowledge of the microbiology of the food product under refrigeration is essential. Obviously all food products do not possess identical safe temperature characteristics. The solution of this problem lies, however, in the hands of the individual operator. The temperature of the refrigerating space will vary from point to point. Since no one rule will apply to all refrigerators because of differences in construction, it is up to the operator to determine the temperature distribution and to arrange the produce accordingly.

Safe Humidity.—The optimum humidity of refrigerating space varies with the product under refrigeration. The relevant literature varies between very wide limits in recommendations for the specific relative humidity needed. In general, a safe humidity is that below which fungi do not grow and which is still high enough to prevent serious dehydration of the product. The critical amount of moisture is characteristic for each species of microorganism and is higher in pure air than in air containing a high carbon dioxide content, *i. e.*, 10%.

Ventilation.—Good air circulation is essential for successful refrigeration. Not only does this circulation aid in maintaining a uniform refrigerating temperature within the refrigerating space, but it also aids in preventing an overaccumulation of moisture in the less accessible spaces. Areas of accumulated moisture provide excellent growing sites for various fungi.

The food product should be arranged for maximum ventilation within the refrigerating space. Some operators prefer ventilating equipment so designed that the air may be circulated through a deodorizing column to prevent the accumulation of odors. Others use fresh air to flush out the refrigerating space; but obviously this system of ventilation requires more refrigeration because of the continuous loss of cold air and its replacement by warm air. Each of the systems has a certain advantage,

the former in its economy and the latter in its control of the composition of the atmosphere. Fruits respire considerable carbon dioxide which, if allowed to accumulate in the system, may cause damage to the food product. In general, the ventilation arranged for should be that which has been shown by practice to be the optimum for the product being refrigerated.

Odors.—More damage to food products is caused by overtaxed refrigeration systems than is generally realized. Meat, for example, develops the so-called "friggy" odor and once so polluted cannot be reconditioned. The apple is also easily affected, for its aroma is extremely pungent and lasting. Musty odors may arise from damp places supporting fungus growth.

Good ventilation and logical refrigerator organization will prevent odor trouble. The foodstuffs held in temporary storage in the refrigerator vary greatly not only in the combinations present in the refrigerator at any one time but also in the proportion of any one product to another. Experience in their handling is a hard and sometimes costly teacher; science can do little else but point out possible pitfalls.

Atmosphere.—The composition of the atmosphere around the food products has much greater importance than is usually assumed. While a large accumulation of carbon dioxide in the refrigerator atmosphere is very damaging to many products, especially such fruits as apples, it does have a very desirable function in the refrigeration of many products, especially meats.

Carbon dioxide in any concentration retards growth of the fungi attacking meat at 32° F. A 40% concentration in the atmosphere completely inhibits those bacteria responsible for the sliminess of chilled beef, while at 15% concentration completely suppresses, for at least 50 days, the onset of rancidity arising from a breakdown of connective tissue by microorganisms. However, in spite of these desirable functions, too high concentrations of carbon dioxide lead to a destruction of the "bloom" of meat. Unless the carbon dioxide concentration is kept under 20%, there is a marked increase in the rate of formation of methemoglobin in both the muscle and the fat, the exposed muscle becoming brownish and the fat becoming bleached. The storage life of chilled pork, mutton, and lamb is extended considerably by the presence of carbon dioxide in low concentrations. On the other hand, the ideal environment for bacon is 100% carbon dioxide because bacon fat oxidizes rapidly even at temperatures below 32° F., in addition to being damaged by fungi and slime forming bacteria. Other food products behave differently toward carbon dioxide. For example, treatment with carbon dioxide is beneficial for iced fresh fish immediately following *rigor mortis*, but is ineffective in restraining bacterial development during rigor.

In the case of apples, an accumulation of carbon dioxide may cause a suffocation of the fruit, a condition called brown heart. Although this trouble occurs principally in transoceanic shipping, the possibility of its occurrence and its effect upon the flavor of the apple must be recognized. Most apple varieties keep in better condition in an atmosphere of 8 to 10% carbon dioxide and a correspondingly lower oxygen content. Obviously the presence in the atmosphere of those substances which might cause flavor changes by adsorption, hydrolysis, oxidation, or other processes must be avoided.

(b) Freezing

Freezing, until recent years, was more or less limited to the dairy and meat industries, and the freezing of various fruits and vegetables was something to be avoided rather than attained. However, the proponents of freezing preservation, after many and severe defeats, have succeeded in placing this form of preservation in the foreground, ranking perhaps as the greatest voluntary contribution to quality control now being practiced by the food industry. Furthermore, it is expected that greater practical extensions of freezing principles will shortly be made available to the food industry.

Too great an emphasis cannot be placed on freezing from the point of view of quality: It provides the most practical method yet devised for supplying the American table all year around with "garden fresh" perishable vegetables and fruits, not only from domestic producers but also from producers in foreign lands. Seasonal variations in production are overcome to a great degree; and waste is reduced by shipping only the edible portions of the products. The process permits retention of the heat-labile vitamins and other necessary nutritional factors, as well as of the delightfully delicate aromas and flavors for which consumers gladly pay the higher price. This does not imply that the canning industry has not made great advances too; but certainly freezing preservation has given the canning industry a very high goal for which to strive. Both methods of preservation have many problems to solve.

Definitions.—American industry generally has adopted the term "frozen pack" to designate the product obtained by the freezing process termed "freezing preservation."

Purpose.—It is the desire of the packer to retain the properties of the fresh food product to as great an extent as possible. This is also the most important problem of the freezing industry, since the degree of reversibility of the frozen product to its original state on thawing largely governs consumer acceptance or rejection.

Effect on Tissues.—Because foodstuffs vary so greatly in their reaction to freezing, an enormous amount of work has been done on the effects of freezing on food products. A glance at the literature serves only to confuse the reader with its emphatic statements and equally emphatic contradictions, but each, of course, with its partial truths. Although opinions differ considerably on the merits of fast and slow freezing, most of the experimental evidence favors the former. Most authorities agree that damage is not due to exposure of the foodstuffs to low temperatures, but rather to ice formation.

From a physiological point of view, the salient feature of freezing appears to be that ice formation occurs mainly in the intercellular spaces of the tissues. The formation of ice effects a concentration of solutes in the liquid phase surrounding the cell, especially an increase in the hydrogen-ion concentration. This increased concentration disturbs the osmotic equilibrium of the cell, causing the removal of water from the cell contents into the intercellular space to form ice and thus causing death of the cell. Also, a dehydration of the protoplasmic colloids is effected which may cause irrevers-

ible changes in structure and function of the cell, in turn reflected in gross effects on tissue quality. This may be traceable to an increase in the viscosity of the protoplasm to a point at which the cell cannot function. Even though water is present in the tissue in both the free and bound state, there seems to be little difference between the behavior of the two during the freezing process. The changes in the tissues as a result of freezing may be considered analogous to "salting out" of proteins, also a dehydration phenomenon.

As stated above, dehydration of the tissue modifies it considerably, causing a possible precipitation of the proteins in the protoplasm, a loss in turgidity, a partial collapse of the cell walls and even the death of the living cells. Since the dehydrated colloids will not reabsorb much water on thawing, the flabbiness of many frozen packs is due to the removal from the cell of water, one function of which was to support the cell walls. Loss of plant juices is not due to a rupture of the cell walls but to an irreversible precipitation of the cell contents after liberation of bound water and water previously present in the cell vacuoles. This water also is not reabsorbed on thawing. Tissues having very thick walls do not show as marked changes as those with thinner cell walls, which explains why certain foodstuffs with tissues largely maintained by cell walls react more favorably toward freezing. The starch content evidently furnishes additional support to the cell, for starchy vegetables are much less changed than nonstarchy foods.

Effect of Rate of Freezing.—These rates are very important in many instances because of their effect on the subsequent condition of the foodstuff.

When the freezing is so rapid that the original spatial distribution of the colloid system is fixed, the original structure in the foods will usually be reproduced by either rapid or slow thawing.

In slow freezing, large ice crystals result and the water is only partially reabsorbed by the damaged cells on thawing. The formation of the larger ice crystals apparently has a greater destructive effect on cell structure, permitting the loss of albumin and salts from the cell. Actually, the plasma membrane is destroyed and plasmolysis occurs. Rapid thawing obviously cannot restore the original condition. With slow freezing, flavor, texture, food value and appearance are adversely affected.

The rate of freezing is of greater importance to packers of animal tissues than those packing plant tissues, although there are some exceptions, depending upon the freezing temperature. In the case of plant tissues, the physicochemical damages are far more serious than mechanical damage: If a peach is cut in half and one half frozen at -100° F. and the other half at 0° F., examination after thawing shows that the former can hardly be distinguished from a fresh peach and that the latter is greatly damaged.

Effect of Rate of Thawing.—Some authorities consider that all troubles involving freezing are traceable to too rapid thawing. If the colloids do not produce a colloidal gel simply on contact with water, the rate of thawing is without effect; but if a sol or gel condition follows contact of the colloid with water, then the thawing should be slow enough to permit the colloid to take up the water provided by melting. In the latter case, rapid thawing might result in a more or less permanent separation

of the colloid and water. However, the amount of water lost through cell leakage is analogous to that lost through cooking, placing the tissue in a saturated salt or sugar solution, or desiccation. As noted, when actual injury to the foodstuff has occurred during freezing, the thawed product is likely to be rather limp.

Drip Loss.—Drip loss is defined as the loss in weight due to exuding, or dripping away, of tissue juices during draining of thawing products for 24 hours. This loss is affected by the rapidity of freezing and the composition of the liquid atmosphere surrounding the product during freezing. With strawberries, drip loss amounts to 19.4 to 44.2%, varying with the sugar content; with apricots, drip loss amounts to 2 to 13.6%. Freezing in dry ice (-78° F. at one atmosphere) gives a lower drip loss than that obtained after freezing at 0° F. (Table 8). Some vegetables show but little

TABLE 8
PERCENTAGE OF DRIP LOSS FOLLOWING FREEZING

Product	At 0°	In dry ice
Sliced apples	1.03	0
Peas	8.4	4.5
String beans	14.5	8.2
Asparagus	23.4	19.2
Strawberries	37.1	29.7

differences in drip loss during thawing after being frozen at the two temperatures. Other vegetables, after blanching and packing in brine prior to freezing, actually gain weight on thawing instead of exhibiting a drip loss.

Effect on Volume.—Many whole fruits and some vegetables burst on freezing. Because of the expansion of the contents during ice formation, containers of juices, crushed fruits, and other liquid or semisolid products may burst on freezing if filled completely. Certain frozen packs may be controlled by the addition of sugar or sirup, which markedly lowers the expansion if present in sufficient quantities (Table 9).

TABLE 9
RELATION OF SIRUP CONTENT TO EXPANSION

Composition of sirup	Expansion on freezing at 0° – 5° F., %
Water.....	8.6
20% cane sugar sirup.....	8.2
40% cane sugar sirup.....	5.2
50% cane sugar sirup.....	3.9
60% cane sugar sirup.....	0

Effect of Enzymes.—Freezing disorganizes tissues and renders them permeable for the liberation of enzymes which, when released during thawing, may cause serious quality changes. Many fruits darken rapidly on the surface because of the coactivity of the oxidases and atmospheric oxygen. Fruits packed without sirup brown severely in freezing storage when packed in containers that are not airtight. More changes in

color, texture, and odor are induced by enzymic action (in addition to the usual physicochemical changes) at temperatures of 20 to 25° F. than at 5 to 10°.

Treatment with sulfur dioxide may be used if it does not affect the character of the fruit or vegetable; but because of delicate flavors and aromas, sulfur dioxide must be cautiously used.

Unblanched vegetables deteriorate rapidly in color, flavor, and odor even when stored at 5° F. They develop a haylike odor and flavor; the initial green color changes to yellowish green and then to yellow when cooked later. These changes are produced mainly by the oxidase enzyme, but undoubtedly other enzymes are also concerned. Although severe blanching destroys all the enzymes, vegetables may also lose their green color and acquire disagreeable odors and flavors by nonenzymic oxidation if stored in free contact with air.

The amount of deterioration which might be expected during storage of the frozen pack may be roughly indexed by determining the catalase activity (Table 10) toward

TABLE 10
EFFECT OF A TWO-MINUTE BLANCHING AT VARIOUS TEMPERATURES ON CATALASE

Temperature, ° F.	Catalase	Quality
140	Present	Deteriorated in flavor and color
149	Absent	Deteriorated in flavor and color
153.5	Absent	Deteriorated in flavor and color
158	Absent	Inferior
167	Absent	Inferior
171.5	Absent	Good
176	Absent	Best quality
185	Absent	Best quality
194	Absent	Texture too soft and skins tough
212	Absent	Defects more pronounced

hydrogen peroxide. In the case of vegetables, if blanched sufficiently to inactivate the catalase the frozen pack can be expected to keep reasonably well; but a more severe treatment than that necessary to inactivate catalase is required to insure better storage properties.

Pectic enzymes hydrolyze the pectin in berries and reduce their gelling properties. Invertase is likewise active during and after thawing, hydrolyzing the sugar sirup surrounding the pack or hydrolyzing the sugar present in the fruit itself. Undoubtedly many other enzyme systems function here too, but their role in the frozen pack industry has not yet been extensively studied.

Effect of Packing in Liquid.—While most freezing preservation operations are carried out on vegetables, fruits, or meats alone, the quality of many could be improved if they were packed in sirup or brine prior to freezing. Berries and certain other fruits will retain their color, flavor, and texture better when packed with sirup than when packed with sugar or with no addition at all. Fruits which darken readily may be kept in their original condition more easily if packed in sirup prior to freez-

ing. Similarly many vegetables behave better if processed in brine. Although the products packed in sirup or brine do not deteriorate as rapidly as the same products packed without sirup or brine, there are two overbalancing disadvantages: it is a decided inconvenience to thaw the solidly frozen mass; and the added weight markedly increases shipping costs.

Choice of Container.—Obviously the container in which the pack is frozen has a very important bearing upon the success or failure of freezing preservation. Adverse chemical, physical, and enzymic changes proceed at a much slower rate if the product is packed in hermetically sealed, airtight containers; vacuum sealed containers are superior to those which are air sealed.

Enamel-lined tin cans are preferred for berries and other colored fruits because they have less effect on color. In general friction-top cans are very suitable for large consumers as well as household trade. They are nearly airtight, prevent the absorption of off-odors and flavors, and are convenient to use. Theoretically, key opening, vacuum sealed, airtight tin containers are preferred to any others in that they neither admit air nor permit evaporation of moisture from the product. The main objection to frozen pack in tin cans of the types mentioned is that the consumer has long associated tin cans with a sterilized product; unthinkingly, he may permit the frozen pack to stand at room temperature too long, and the product may spoil and become harmful. Frozen pack in tins therefore must be clearly labeled to caution against such treatment. Another objection to packing in tin is that many products do not require airtight containers, so that the extra expense of tin is not justified. These products may be packed after freezing in lined, tightly sealed cases to reduce the tendency for evaporation of moisture and afford much less opportunity for absorption of storage odors and flavors.

Paraffined cardboard cups are fairly satisfactory for foods packed in sirup or brine. Cover designs include two popular models, one in which the cover slips into a groove near the top of the container, the other with the top crimped into place by rolls similar to tin cans. While these containers are inexpensive, convenient, and very light in weight, they permit considerable oxidative changes and admit off-flavors and odors. A much more popular paper container consists of small paraffin-impregnated cartons lined with a waterproof lining, a form of packing conveniently handled in the continuous freezing operations. Some vegetables, especially peas, are also packed in fiberboard boxes lined with wax paper; with this type of container the vegetables are first frozen in air in a rapid freezer, then packed in the frozen condition without liquid in boxes which are sealed and stored immediately at or below 15° F.

Glass containers have also been used but are heavier, more costly, and obviously require greater care in handling.

Paraffin-lined spruce barrels up to sizes of 50 gallons have been used for some berries. In this case the berries are packed in dry sugar and frozen; but the slow rate of cooling and the relatively great distance to the center of the barrel cast some doubt on their general acceptance. Once the barrel has been opened, the contents must be used immediately.

Heat Loss.—Heat loss, sometimes termed cold penetration, can be considered as the reverse of heat penetration. The rates of loss are governed by the same laws with but one exception—that cooling is carrying away of heat by conduction only, whereas heating is carrying by convection as well as by conduction. As might be expected, ice formation first occurs at the can-product interface, ice formed slowly conducting heat from the center to the refrigerating medium.

Heat loss rates vary with the nature of the product, but the differences are much less than those observed in heat penetration. The temperature differential between the product and the surrounding atmosphere governs the rate of heat loss; generally the differential is much less in freezing operations than in heating operations. The cooling of products in small containers is five times more rapid in dry ice at -110° than in air at -2° F. The freezing period (the period of constant temperature during and after ice formation) is very much shorter in dry ice than in air.

TABLE 11
EFFECT OF COOLING ON BERRIES PACKED IN DRY SUGAR (2:1)
AT 61° F. IN 50-GALLON BARRELS STORED AT 14° F.

Hours after storage	Temp., ° F.	Bacterial action
24	53	favorable
48	42	favorable
72	34	unfavorable
FROZEN		
Temp. of freezing, ° F.	Hours to reach 40° F. ^a	
0	36	
15	48	
30	84	

^a Unfavorable for bacterial growth.

The presence of brine or sirup likewise has a decided effect upon the cooling rate. Cane sugar cools more rapidly than water, a cooling continued without interruption until the temperature of the freezing room (below freezing) is attained. Water and light sirups, however, cool steadily until they begin to freeze, and remain at freezing temperature until completely frozen, when their temperature again falls until reaching that of the freezing room. In contrast, heavy sugar sirups do not freeze at all, their cooling curve being parallel to that of dry sugar. Thawing curves are more or less the reverse of cooling curves, in that there is a rise to the melting point, a steady temperature during melting, and then a slow rise to room temperature.

The rate of heat loss is affected markedly in batch freezing. The cooling of tin cans or paper containers in cases is naturally very much slower than that of the same small containers standing individually in the freezing room and so arranged that cold air can circulate freely between them. Experiments show that, when packed in cases, containers in the upper corners are cooled most rapidly and those in the center positions, most slowly. It is clear from Table 11 that slow cooling results in considerable

spoilage. Precooling of the fruit in shallow crates is advocated to reduce spoilage to a minimum.

The Product.—Freezing preservation is not suitable for all food products. Probably the best criterion for determining the suitability of a food product for freezing preservation is the desire of the consumer and his willingness to pay the higher retail price. It is easily justifiable for most of the important varieties of berries, avocados, persimmons, sour cherries, tropical mangoes, Lima beans and possibly several varieties of green pod beans, spinach, corn on the cob, peas, and others. A general rule might be that freezing preservation is desirable in those cases in which the food product itself possesses a delicate texture, flavor, or aroma, or when it is necessary to send the food long distances, such as in transoceanic shipping.

In contrast, there is little justification for freezing preservation of bananas, citrus fruits, pears, prunes suitable for drying, apples, peaches (other than dessert varieties), pineapple, cut corn, tomatoes, pumpkin and the like, for these are equally well, if not more satisfactorily, preserved by canning methods and are generally preferred by the consumer in the canned form.

EQUIPMENT

(a) *The Absorption Machine*

The absorption refrigerator differs from the familiar compression type of apparatus in that a direct application of heat is employed to produce a refrigerating effect. The apparatus consists essentially of a chamber, known as a generator, fitted with a steam heating coil and containing a strong aqueous solution of ammonia. On application of heat to the solution, evaporation takes place. The ammonia gas passes off through an upright chamber fitted with a series of iron trays. The greater part of water vapor carried over by the ammonia is trapped and allowed to drain back into the generator while the ammonia passes on to a rectifier where any remaining water is removed. The anhydrous gas is liquefied in a condenser and then passed through a regulating valve to an evaporator, where, upon release of the pressure, the ammonia again evaporates, effecting the refrigeration. The gaseous ammonia is reabsorbed by water and the solution returned by pump to the generator. The pump, the only moving part in the absorption system, requires very little power for its operation. The greater efficiency of the compression type of machine has led to its being preferred to the large-scale absorption machine except where waste heat or an inexpensive heat source is obtainable. The latter is, however, extensively applied to smaller units which utilize gas or kerosene as the source of heat.

(b) *Compressors*

The principle of all types of vapor-compression refrigeration machines is essentially the same, that is, they are heat engines which effect refrigeration by utilizing the heat absorbed by the expansion of a refrigerant like sulfur dioxide. There is a considerable resemblance among the various designs. The most marked development in recent

years has been the adoption of high speeds, enclosed construction, and forced lubrication. High-speed types of compressors have proved durability and reliability. It must be remembered, however, that piston speeds have not been increased to the same extent as the revolutions of the driving mechanism. The kind of valve used for the release of the refrigerant is also varied, but generally is one of three types: a light plate, whose main drawback is that it requires greater clearance, which reduces the compressor capacity, a defect offset by the compactness of the machine; a ring valve, which has the same defects and advantages as the light plate valve; and a sleeve valve, borrowed from the automotive industry. Multistage machines are recommended for the especially low temperatures needed in the manufacture of liquid ammonia and dry ice.

Attempts have been made to avoid the fall in efficiency of carbon dioxide machines at high temperatures by an apparatus which takes its charge at two different pressures, the compression being carried out at one stroke of the piston. The principle is simple: Some of the gas is liquefied in a separate receiver; the nonliquefied gas is returned to the compressor and is not circulated through the evaporating coils, but is expanded to a predetermined value intermediate between the condenser pressure and the evaporator pressure; a trunk piston is used in the compressor, and the gas from the receiver is introduced when the piston has traveled part of a stroke after having already drawn in some gas from the evaporator. This partial expansion is the important feature. The free expansion cooling is proportional to the ratio of expansion, and the work done in compression depends on the difference in pressure. There is a distinct saving by not reducing the pressure to a low value.

Although the essential principles in design and construction remain the same, the design of the compressor refrigerator is necessarily modified according to the refrigerating media. Each refrigerating medium has its own peculiar characteristics and special advantages. The refrigerants generally used in smaller units, especially household units, are methyl and ethyl chloride, sulfur dioxide, Freon (dichlorodifluoromethane), and others.

Water jackets have been employed in the construction of some compressors in order to eliminate part of the heat of compression. This reduces superheating of the cold suction gas, but only a small portion of the compressor cylinder can be jacketed. It is questionable whether the gain in efficiency is worth the added complication of the castings involved.

(c) Condensers

The function of the condenser in any refrigerating machine is that of a heat exchanger; the gas passing through is liquefied by transferring the heat of compression to the cooling water. The design is such that the gas does not come into direct contact with the condensing medium, which would be the ideal arrangement from a heat transfer point of view. The condenser therefore must be constructed of a good heat conducting material; and the flow of water must be as rapid as possible and moving

in a countercurrent direction. There are three main types of condensers now used: the submerged, the open, and the double pipe (shell and tube).

Submerged Type.—The submerged condenser requires 30 square feet per ton of refrigeration (equivalent to 80 feet of one-inch pipe), and is especially adapted to marine installations. It is compact and enclosed, but requires a greater cooling area and a greater quantity of cooling water than other types because the water circulation is usually sluggish, although agitators are sometimes used to improve the rate of circulation. Its compact nature makes the cleaning and examination of the coils difficult—the refrigerant may leak and escape detection for a considerable time.

Open Type.—Open condensers require about 10 square feet per ton of refrigeration (equivalent to 16 feet of two-inch pipe), and are usually erected on the flat roof of a building or in some similar position. Usually they are boxed in to permit ready access of air and also to prevent the cooling water from being blown off the pipes by high winds. The typical open condenser consists of a series of vertical banks of coils fitted at the top with a water header which discharges an even flow of water over all the coils. In the larger installations it is so arranged that the water can be continuously recirculated, water additions being required only to replace that lost by evaporation and wind.

Double Pipe Type.—Double pipe condensers require 7.6 square feet of surface per ton of refrigeration (equivalent to 18 feet of 1.25-inch pipe). The cooling medium is circulated through a pipe which is itself enclosed in another pipe of larger diameter. The gas to be condensed is circulated through the annular space between the two. A whole series of pipes are connected to form a coil in which the gas enters at the top, leaving the bottom as a liquid, with the cooling water following exactly the reverse path. This type of condenser is very efficient, and can be installed practically anywhere. While the end fittings appear likely to give trouble, they behave very well under conditions of actual practice.

Shell and Tube Type.—The shell and tube condenser consists of a welded steel shell constructed around the water circulating tubes. It is an interlaced coil type requiring about 25 square feet of surface per ton of refrigeration (equivalent to 60 feet of 1.25-inch pipe). Its application has not been widespread.

(d) *Evaporators*

The evaporator is the part of the installation in which the refrigeration is effected. In some cases the evaporator is actually installed in the chamber or apparatus it is desired to cool, that is, it is a direct expansion machine.

Direct Expansion.—A series of pipes are arranged about the walls and sides of the room, cabinet, or apparatus to be cooled. The liquefied refrigerant is allowed to evaporate in these coils and in so doing absorbs heat from whatever substance is in proximity to the piping. Ordinary cold room moisture is deposited on these pipes in the form of snow, and must be periodically removed to prevent loss in efficiency in the heat transfer. If, however, ceiling coils are employed and the room is occasionally

operated at temperatures at or above 32° F., some form of guttering must be employed to catch the moisture condensing on the pipes or it may drip on, and damage, the goods stored below. See pages 166 and 169.

In general, it is advisable to separate the various pipe circuits on the walls and ceiling, to provide each bank with its refrigerating liquid, and to equip them with suction stop valves in order that the conditions prevailing in the chamber may be more closely controlled.

The arrangement of all valves and gages should be in the engine room for closer supervision by the engineers. However, unless all cold rooms are on one floor and circuits are practically the same length, better results may be obtained by placing the controls outside the chambers they control.

Brine Coolers.—Another evaporator consists of a series of closely nested coils erected in a tank through which brine is continuously circulated. The brine is cooled by contact with the cold evaporator coils; as the cold brine is circulated through the pipe grids in the cold room, the heat is extracted from the atmosphere in contact with the piping. Occasionally the construction of the brine cooler is reversed, in that the brine is circulated through a nest of coils while the refrigerant is allowed to evaporate in the casing surrounding them. This latter method is popular with some manufacturers of ammonia machines. Baudelot-type coolers, constructed similarly to open-style condensers, are also often employed.

(e) *Forecooling Tanks*

Forecooling tanks are used to effect considerable economies in the production of ice. Water used for ice production is received at a comparatively high temperature, especially in the summer. These tanks receive the water and hold it for a short period before passing it into the freezing cans. They are insulated on the sides and bottom; the top has an insulated cover which is easily detached to facilitate cleaning. Cooling is effected by a return of the gas from the evaporators through a set of coils in the tank. The temperature of the water is reduced to a reasonable level, thus easing the work of the brine in the freezing tank, insuring more complete evaporation of the refrigerant, and helping to make certain that only dry gas is returned to the compressor.

(f) *Liquid Receivers*

Often provided with refrigerating machines, they give storage space for excess refrigerant and insure that only condensed refrigerant passes through the regulating valve. Since liquid receivers also provide storage space if it becomes necessary to pump out the circuit in order to make repairs, they should be of ample size. Their use eliminates the necessity of periodical addition of small quantities of refrigerant.

(g) *Vacuum Refrigeration*

Vacuum refrigeration is a comparatively new system of refrigeration, entirely different in operation from the generally accepted methods of refrigeration. Water or

brine solution and steam are usually employed to effect the refrigeration. The operation depends upon a physical phenomenon: lowering the absolute pressure in the evaporator until it is at a pressure equivalent to the required temperature. If the absolute pressure in the evaporator is lowered until it is less than that of the vapor pressure of the liquid, the liquid will boil; this vaporization will continue until the temperature has fallen to a point at which the lowered vapor pressure equals that existing in the evaporator.

In this process of "boiling" under reduced pressure the external work is at a minimum. It is therefore necessary that the latent heat of vaporization be obtained from the liquid itself, and so the temperature falls. The method is very simple and economical.

MATERIAL

(a) *Refrigerants*

Ammonia.—Ammonia is the most commonly used refrigerant for land installations. The pressures at which ammonia machines operate are those common to steam engine practice. The thermal extraction per cubic foot of ammonia is high and the heat of vaporization amounts to about 530 B.t.u. per pound. The ammonia should be absolutely anhydrous and practically free of other impurities.

Ammonia is readily soluble in water; large quantities may therefore be lost from the circuit through leakage. The presence of 0.03% ammonia in the atmosphere is toxic to the operators. Usually, however, leakage occurs from the condensing coils into the cooling water, although it may occur from the direct expansion pipes into brine tanks. Losses attributed to ammonia may be detected by nesslerization of the suspected water.

Brines.—Brines are used in refrigeration to obtain a medium capable of being cooled to a comparatively low temperature without freezing. Calcium chloride brines are more commonly employed because they are less corrosive than other brines. The saturation point of this brine is far outside the temperatures and densities used, eliminating the danger of the formation of deposits in the pipes and of sludge in the tanks. The density generally employed is approximately 1.2 at 60° F. Sodium chloride brines have several disadvantages: they are more corrosive than calcium chloride brines and, being less soluble, may crystallize out in the pipes and tanks during operation. Magnesium chloride should be absent from these brines because of its tendency to corrode the equipment and to form a sludge in the tanks.

Carbon Dioxide.—In spite of certain disadvantages, carbon dioxide is a refrigerant which is preferred by some, especially in marine work. It is less efficient than ammonia; more work of compression is wasted in the vapor compression machines; and the thermal extraction per cubic foot of the gas once used is the highest of all refrigerating media known at present. Its advantage lies in the fact that it is less toxic than ammonia, since over 5% must be present in the atmosphere before a human being is rendered unconscious. In marine work, ammonia machines must be housed away from the engines; since carbon dioxide machines may be placed right in the engine

room, the space and supervision they require are less. In the tropics, however, the temperature of the cooling water, coupled with a 10° temperature differential between the gas and the cooling water, may approach the critical temperature of carbon dioxide, approximately 87° F., so the power required per unit cooling would be over twice that required for ammonia systems and the condenser employed should be highly efficient. These high pressures require very strongly constructed equipment and a carefully installed plant.

Dry Ice.—Dry ice is solid carbon dioxide produced by freezing carbon dioxide (obtained from natural wells and springs, from the combustion of coke or as a by-product of the brewing industry) in a cooler medium, as, for example, liquid air. In practice, it is produced in chalky blocks having a density of about 1.4. In contact with warm substances, dry ice sublimes directly to produce a dry, odorless, noninflammable gas. The latent heat of vaporization is about 250 B.t.u. per pound. The cold gas is heavier than air, descends upon sublimation, drives the air from the chamber, and envelopes the material to be cooled with a cold, sterile atmosphere.

Dry ice is prepared by two general methods. In one, the liquid carbon dioxide is adiabatically expanded through a nozzle at about atmospheric pressure. About two-thirds of the liquid is evaporated and one-third is frozen to snow, and the evaporated gas is collected and reliquefied. The snow is compressed to a hard block by a hydraulic press at a pressure of 50 to 100 atmospheres. In the other method, the liquid carbon dioxide is adiabatically expanded through a needle valve, a nozzle and diffuser of special design, to a triple-point pressure of 5.28 atmospheres absolute, whereby the freezing point of the carbon dioxide is reached. This produces an intimate mixture of snow and liquid which accumulates upon a filter at the base of the generator. The size of the cake is controlled by timing the operation. When sufficient snow has been collected, the generator is opened to the atmosphere. The subsequent decrease in pressure causes some of the liquid to evaporate. Heat is abstracted from the mass by virtue of its latent heat of vaporization, and in this way the entire cake is frozen to a hard, solid block. The evaporated gas is returned to the liquefier through a filter. When the manufacture of the block is completed, the lower cover of the generator is opened and the block slides out. Block sizes are obtained up to 8 feet by 10 inches; these may be cut into pieces of any required size by a saw.

Probably half of the dry ice produced is used by the ice cream industry, although a considerable amount is used by railway companies and others engaged in the transport of perishable foodstuffs. The preservative effect of the carbon dioxide gas is at least as important as its refrigeration properties. Dry ice used for refrigeration requires well-insulated equipment. It is necessary to have scientifically designed apparatus for controlling the temperature. One hundred pounds in insulated drums lose about 7 pounds per day; and 25-pound cartons lose about one-half pound per hour.

(b) Insulating Materials

The function of insulation is to hinder as much as possible the ingress of heat into refrigerated spaces. The more efficient the insulation and the more thoroughly this

duty is carried out, the more easily and economically can the desired low temperatures be maintained. Obviously the success or failure of any refrigeration or freezing operation is largely governed by the efficiency of the insulation.

Another function of insulation is that it reduces the gain or loss of heat through transmission by direct radiation.

Vacuum is by far the best heat insulator and the next best is probably a gas in a completely still state. It must be remembered that a simple air space between two walls is not a still air space, that convection currents circulate within it. Naturally these increase enormously the transmission of heat from one wall to the other.

Insulating materials obviously are not physically homogeneous solids but rather consist of an aggregation of solid particles (or fibers) and air cells. The insulating properties are due to the subdivision of the air space into a large number of minute air cells and are to be attributed solely to the poor heat conduction of the material itself. For example, asbestos in the form of solid blocks conducts heat rapidly, but when subdivided into small fibers becomes an excellent insulator with contact resistance at numerous points. Actually, there is a small volume of material relative to the total volume occupied. The result of surface resistance to air motion is such that there is only a very small temperature differential between opposite cell faces.

It is clear that the part played by insulation in the installation is one of greatest importance. When refrigerating equipment was first used, very many materials were employed, sawdust and shavings, hair felt, corn and rice husks, charcoal, strawboard, feathers, etc. Modern practice has concentrated mainly on two substances, asbestos and cork in their various forms. However, other materials have been utilized for low-temperature insulating purposes, among which are hair felt and wool felt, cellular expanded rubber, wood pulp as strawboard, sponge rubber, glass wool, and fiberboards. Recently, considerable work has been done upon the insulating value of metal foils.

The presence of moisture in any form in insulation is a serious matter. Cork insulation is the least affected. Every care must be taken during construction to guarantee against the access of moisture to the insulation. Its chief danger in an insulated volume is that it catalyzes the rotting of the woodwork supporting the insulation. It is less expensive to prevent the access of moisture during construction than to repair the damage caused by it at some later date.

The exterior finish of all insulation has to be chosen with regard to several circumstances: It must be strong enough to withstand the normal wear and tear of stacking and handling goods; and it must be nonabsorbent or it will retain odors of any strongly aromatic product. The release of such odors probably would taint susceptible goods stored at a later date. Insulation with a porous surface which may harbor mold spores and furnish favorable ground for their development may be protected by coating with varnish or enamel.

Brine or suction piping of the refrigerating unit requires insulation. Various manufacturers supply ready moulded forms to fit the various pipes. Here again extreme care must be taken during installation to exclude moisture.

Iron or steel columns which may occur in cold chambers should also be insulated. Insulation of rooms and tanks should be of a thickness proportional to the temperature differentials except where such a thickness has been reached that the additional surface area presented to the atmosphere tends to discount the value of the extra heavy insulation.

Pure Corkboard, Baked.—This has very low conductivity, is nonhygroscopic, free of capillarity, noncorrosive, light, stable, and fire-resistant but not fireproof, and possesses sufficient mechanical strength for most conditions under which it is likely to be used. If adequately protected, it will retain its efficiency indefinitely; if not sufficiently protected, it is subject to dry rot and cracking.

Corkboard with Foreign Binder.—This material is inferior to pure baked corkboard. Its conductivity is not much lower but it is less stable and is likely to decline in efficiency. It is more inflammable than pure corkboard. Cork slabs are usually erected either with cement or bitumen and require no timber retaining work. When attached to existing walls or ceiling, some method of spiking the first layer, in addition to the bitumen or cement, is advisable. Insulation on ceilings or walls is usually finished with a hard setting cement of a waterproof nature. Floor insulation needs more protection for it is subject to the harder wear of trucking and stacking. A granolithic finish carried 5 or 6 inches up the side walls and laid on several inches of good concrete is frequently employed. Natural rock asphalt is also capable of making a satisfactory, hard wearing surface; when properly erected and cement-finished it is regarded as practically fireproof. Even unprotected brick exposed to flame only chars it, and there is no actual burning.

Granulated Cork.—This product is very useful for filling irregular spaces, especially for insulation of a ship's hold. It has a very low but somewhat variable conductivity, which is influenced by the size of the granules and the density of the packing. However, this density is likely to change under vibration. Granulated cork is less fire-resistant than baked corkboard. Care must be taken during installation to see that the packing into insulation spaces is sufficiently thorough, thus reducing settling to a minimum.

Asbestos.—Asbestos is an odorless, entirely mineral product and therefore not attacked by vermin. Its disadvantages are those common to all loose insulators: it is likely to settle down, leaving air spaces through which heat can leak fairly readily; it also has a tendency to absorb moisture from the atmosphere, thus reducing its efficiency. These defects may be minimized by care in construction. When it is packed to a density of about 10 pounds per cubic foot, good insulating properties are obtained. The only advantage in packing to a greater density is the reduction of the likelihood of settling. The insulation should be made airtight—the face work on the room side can consist of twin layers of facing separated by one or more layers of waterproof paper, while the surface of the wall should be completely covered with heavy waterproof felt. Wooden studding should be fixed to the inner side of the facing in order to hinder the settling of the insulation.

Hair Felt and Wool Felt.—These materials are chiefly used on pipes conveying

brine, ammonia, or other cold liquids or gases. Sometimes they are used in small refrigerators, iceboxes, and cold storage vans. Their principal merit as pipe insulators is their flexibility, which enables them to withstand contraction and expansion without breaking open and also permits a close contact with the surface of the pipes. For this purpose they are usually constructed and sold in sectional lengths, although in some cases it is preferable to build the insulation directly upon the pipes, interlaying with special binding and waterproofing materials. The conductivity is very low but variable.

Cellular Expanded and Sponge Rubber.—Cellular expanded rubber possesses very low conductivity, is free from capillarity, and withstands vibration and the action of water. It is light in weight and has a low ignition point. Sponge rubber differs from expanded rubber chiefly in having a higher density and conductivity.

Insulating Boards.—These are usually composed of wood pulp or strawboards. They are chiefly used for maintaining a uniform temperature in buildings, as well as for minimizing the condensation of moisture on walls and ceilings of rooms where steamy atmospheres prevail. They can be cut, drilled, and sawed as readily as wooden boards, and easily erected. Some types are verminproof because of the binding material or composition with which they have been treated. They are moderately fire-resistant, and have an insulation value about three times that of wood of equal thickness. Insulating boards can be papered, painted, plastered, or stuccoed.

Glass Wool.—Glass wool possesses very low heat conductivity and is free of capillarity. It does not disintegrate under the action of water; its density does not change easily with vibration; and it is fire-, rot-, and verminproof. Glass wool is difficult to handle and its particles may affect the skin and lungs of workers.

Cellular Concrete.—This material possesses the unusual feature of being obtainable ready-made in the form of bricks, slabs, or pipe shells. Or it may be made by the user on the site where required, and may be poured into spaces or forms of any shape. It has a low specific gravity, may be used in both low and medium temperature insulation, and is odorless, noninflammable, noncorrosive, and rot- and verminproof.

(c) *Noncondensable Gases*

Air is the principal noncondensable gas which finds its way into the refrigerating circuit. Its presence entails the performance of a considerable amount of nonproductive work by the compressor. The air usually tends to accumulate in the condenser, so that provision for a purge valve in the top of the condenser is advisable. In order to eliminate air and yet avoid loss of the refrigerant, the following operations should be performed. With the outlet valve closed, the compressor is kept running until a high pressure is reached, and then stopped. The ammonia inlet valve is closed. The pressure at first falls slightly and then remains steady. The inlet valve is then opened and the compressor restarted until the original pressure is regained. The compressor is stopped but the water supply to the condenser maintained. The condenser should then be found full of liquid refrigerant. The pipe from the purging valve is led into

water and the valve opened slowly. When the bubbles appearing from the end of the tube begin to diminish, it is assumed that the air has been blown out. The valve is closed when the bubbles have practically ceased.

METHODS

Fresh-N-Ice slow freezing technique consists of holding the product to be frozen in brine tanks operated at 8 to 10° F. for 6 to 24 hours, depending upon the size of the container and the nature of the pack.

Bryan's carbon dioxide dry ice system is used mostly with meat products. Freezing is carried out at -35° F. The frozen meat is then wrapped in a moistureproof Cellophane and put into double-waxed cartons. In this system, 1 pound of dry ice freezes 4 pounds of beef or 6 pounds of pork.

Hoveman's freezing technique consists of encasing the food product in a close-fitting, flexible membrane such as rubber, rubberized fabric, Cellophane, and the like. The covered product is then sprayed by the refrigerant.

The *Crider-iced* method, based on freezing the food product from the inside out, is especially adapted for use on poultry. The refrigerant is circulated through paraffined paper tubes within the object to be frozen.

Direct immersion into brine methods are generally applied to fish like whitefish, haddock, and cod. These are frozen in brine at 4° F. and glazed prior to storing at 4 to 22°. Fatty fish, such as herring, are best frozen rapidly in summer or autumn in such a manner that they are free of salt, which activates enzymic degradation. Brine-frozen fatty fish which have been carefully washed, glazed, and stored become rancid during 4 months' storage at 19° F., while those fatty fish frozen out of contact with salt keep well for 6 months or more at 19° F.

The *Cold Pack* method has been used for 20 to 30 years on fruits and berries, which are packed in 50-gallon barrels either with or without the addition of sugar and then held around 0° F. until frozen. Higher temperatures, up to around 14° F., are satisfactory provided that the fruits and vegetables are blanched or partly cooked in sirup or water before freezing.

Cold air, or the *sharp*, freezing method has been only partially successful because of the very low rate of heat transfer. See page 322.

Ottesen's brine method is very similar to the direct immersion discussed above and likewise is used mainly for fish. The fish to be frozen are immersed in brine at a temperature of 2.2° F. and frozen with reasonable rapidity. The brine, however, is contaminated after repeated freezings, its penetration into the tissues of the fish being a means of carrying this contamination into succeeding batches of fish. Deterioration of fish frozen by this method is likely to be rapid because the natural protective mucilage of the fish is removed by immersion in brine.

Cook's oven method employs a small, metal, ovenlike chamber with hollow walls through which brine is circulated at -25° F. The food product to be frozen is placed on the shelves within the chamber and the freezing completed in about 50 minutes.

Kolbe's pan method is probably the most unique. A tank constructed in the floor

of a cold chamber and filled with brine at 20° F. is divided by a ribbon of galvanized sheeting into a continuous snakelike path. The article to be frozen is floated along the spiral in a shallow pan at such a rate that, on reaching the delivery end of the tank, freezing is complete. The food requires about 45 minutes to traverse the spiral path through the freezing unit.

In *Bloom's* cold air method a room is equipped with false ceilings above which a series of cold brine sprays are arranged. The air is chilled by contact with the sprays and descends through ducts in the ceiling, where it absorbs heat from the products to be frozen which are arranged below. The warmed air rises through another set of ducts to enter the spray chamber where it is rechilled, and descends again to recommence the cycle.

The *Birdseye* process is the most elaborate in that the freezing unit is designed to handle uniformly sized packages continuously. The freezing unit consists of two endless monel metal belts enclosed in a tunnel, and maintained at -50° F. by calcium chloride brine. The belts are arranged one on top of the other and move in the same direction and at the same speed. They are adjusted so that there is a clearance of 3 to 4 inches between the top of the lower belt and the lower surface of the upper one. The article to be frozen is placed between the two belts and set off on its journey to the delivery end. Because of the good double contact, heat transmission is rapid and the freezing time is short.

Zarotschenzeff's fog system is practically identical with Hoveman's method. The product to be frozen is subjected to a spray or sprays of atomized low-temperature brine. The spraying technique has a definite advantage in that irregular shapes, sizes, and products may be easily frozen.

Smedley's package method consists of washing, shelling, grading, or cutting up vegetables and packaging them in various sizes of Cellophane bags which are in turn put into hygienic, waxed boxes. The packaged product is then exposed to extremely low temperatures.

A *polyphase* or *flash* process has recently been proposed for use with soft fruits. It is a modification of the immersion method. The fruit is pushed along in a freezing solution by a screw conveyor at a rate slow enough to permit freezing. The most important part of this method is the freezing solution, which must have a freezing point below 0° F., and a low viscosity, of about 500 centipoises at 5° F., because the liquid must be pumped. The solution contains about 57% total solids as sugars, composed of about 10% sucrose, 54% levulose, and 36% dextrose. The excess solution is removed from the fruit, without damaging the fruit or the syrup, by means of a semi-continuous, completely automatic centrifuge. About 1% syrup is permitted to remain on the fruit to coat it and thus greatly reduce the possibility of adverse surface effects from oxidation.

Haslachler's package method consists of preparing the food product exactly as for canning and packing in waxed cartons. The fruits and berries are covered with sugar sirups, and the vegetables with water or dilute salt solutions. A cardboard disk, used to submerge the product and to pack it more closely, has perforations to allow for the

expansion of the liquid during freezing. The containers are packed into a number of long metal cylinders slightly larger in diameter than the containers themselves. These cylinders protect the container from the brine and serve to conduct the heat from container to the brine. The freezing is carried out in an agitated brine tank at about 10° F. After freezing, the cylinders containing the filled cartons go to a thawing well where they are immersed for a few minutes to overcome adhesion. The containers with the frozen product are then emptied out, thoroughly frozen and ready for storage and shipment.

TEMPERATURE CONTROL

(a) General

Since the whole art of refrigeration is the control of temperatures (see page 313), obviously provision of instruments indicating the efficiency of that control is very important. In general, two types of thermometers are used, the mercury or spirit type which is a direct reading thermometer, and the distant reading type. The latter instrument appears in three general forms—mercury steel, electrical resistance and vapor pressure types—with or without recording devices.

(b) Mercury Steel Thermometers

These are similar to the ordinary glass thermometer in principle. The mercury is contained in a steel bulb connected to a pressure gage by fine capillary tubing up to 50 feet long. Naturally, the longer capillary gives a more improved performance. The quadrant and pinion of the instrument are often replaced by a Bourdon coil.

(c) Electrical Thermometers

These work on the principle of the variation in temperature with the resistance offered by metal to the passage of electric current. The resistance end is placed in the space where the temperature is to be measured and is connected by a Wheatstone bridge circuit to a moving coil galvanometer, which is calibrated to give direct temperature readings. It is possible to have the galvanometer installed in a central position and to determine the temperature of several points at will by the use of a multipoint switch.

(d) Recording Devices

The recordings made with these thermometers are usually on tape or a circular chart driven by a clockwork mechanism.

In the tape type of recorder, the galvanometer pointer is poised just above the surface of the chart. Interposed between the chart and the pointer is an inked ribbon similar to a typewriter ribbon. Above the pointer is a cam-operated chopper bar which at regular intervals falls on the pointer and depresses it onto the chart surface. The presence of the inked ribbon results in a fine dot record of the galvanometer pointer position, and hence of the temperature. Usually the chart records 3-minute intervals and the 24-hour record.

In recorders employing a circular chart, the galvanometer arm is fitted with an ink-filled stylus which rests lightly upon the rotating chart, giving a line record of the changes in temperature. Obviously this is not quite so sensitive to temperature changes as the tape type, and the temperature record is inclined to lag slightly behind the operating temperature.

3. Dehydration and Drying

GENERAL

The discovery that the drying of foods is a suitable method for preserving some foods until needed is lost in antiquity. Dried corn and the like were buried along with the corpse in some sort of a religious ceremony by early Egyptians, mound builders, and cave and cliff dwellers. The Indians showed the pioneers in our country how to preserve their surplus meats, fruits, and other products by drying them in the sun, a method still used extensively by many throughout the Middle West. The history of the drying of foods reads like a fairy tale, but space does not permit any extensive discussion of it here.

(a) Water Content of Common Foods

The amount of water contained in common foods is surprising. A casual glance at Table 12 will show that enormous savings in space, packaging, and shipping charges

TABLE 12
THE MOISTURE CONTENT OF SEVERAL COMMON FOODS

Food	Water, %	Food	Water, %
Apples.....	85	Fish.....	68
Apricots.....	85	Grapes.....	77
Asparagus.....	94	Lemons.....	89
Bananas.....	75	Lettuce.....	94
Beans, Lima.....	68	Milk.....	87
Beans, string.....	89	Onions.....	87
Beef.....	76	Oranges.....	87
Berries.....	85	Parsnips.....	83
Cabbage.....	92	Peaches.....	89
Cantaloupe.....	90	Pears.....	81
Carrots.....	88	Peas.....	75
Celery.....	95	Pineapple.....	89
Cherries.....	81	Plums.....	78
Cucumbers.....	96	Potatoes.....	77
Currants.....	85	Strawberries.....	90
Eggs.....	70	Tomatoes.....	94
Figs	79	Watermelon.....	92

can result from the drying of food products. However, it must be remembered that the problem is not so simple as stated, and that we are often confronted thereby with flavor, color, texture, and other undesirable changes.

(b) Effect of Dehydration

Dehydration and drying (see page 283) concentrate the food value of a product 5 or 8 times or even more. The removal of water results in a shrinkage which permits close packing. The food may even be compressed into blocks or tablets which can readily be stored and shipped in waterproof paper containers, thus eliminating not only heavy expensive containers but also the water added during processing. For example, one ton of fresh peaches, when processed, canned, and boxed in cartons, weighs about 2800 pounds, whereas the same original amount of peaches when dehydrated weighs 350 pounds. In the case of peas, the weight following usual treatment is 4300 pounds, while the dehydrated product weighs 350 pounds. Such a reduction in bulk is of great importance during wartime—at the end of 1917 over 2500 dehydrating plants were in operation. After that war there was a sudden slump in consumer demand for most of the dehydrated foods used by the army, although certain dehydrated fruits retained their popularity.

SUN DRYING

The simplest method of drying consists of exposing either the whole or cut fruit in trays to the sun until the fruit is one-half or two-thirds dry, and then stacking the trays in such a manner that the prevailing wind may freely pass between them. When sufficiently dry, the fruit is sorted and stored in bins or in piles on wooden or concrete floors to undergo sweating, *i. e.*, equalization of moisture content and softening of the skins. Some fruits, such as grapes, are dried about 5 days on one side, then turned and the drying continued.

RELATIVE MERITS OF SUN DRYING AND DEHYDRATION

Dehydration is rapidly increasing in importance because it gives a product which, when cooked, more nearly resembles the cooked fresh fruit in color and flavor than the product obtained by sun drying. The dehydrated product is usually more sanitary and of a higher quality because of more adequate control during processing. Dehydration requires less factory space and prevents material loss through rain and inclement weather. Dehydration is somewhat more costly, but the superior quality of the product commands a higher price and gives a higher yield of a superior cooking product. Sun drying permits a ripening period for slightly immature fruit. Therefore care must be taken to select only mature fruits or slightly immature fruit in order to prevent overripening during drying.

AIR DRYING

Dehydration of foods may be carried out in air, in superheated steam, *in vacuo*, in inert gas, or by direct application of heat. Air is usually used because it is less costly, it is more convenient to install and operate dehydrators using air as the medium, overheating is easily avoided, heat is conducted to the product to be dried, and the liberated moisture is conveyed from the product to the atmosphere without requir-

ing expensive moisture condensers. Air drying permits gradual drying, thus avoiding loss of juice by dripping, and reduces the tendency for the fruits to discolor and scorch.

(a) *Air Requirements*

Approximately 1000 B.t.u. are required to evaporate one pound of water from the food product. If the air drops 40° in temperature, for example from 150 to 110° , in the drying chamber, it would require 1750 cubic feet of air to furnish this amount of heat. If the air is dry on entry into the drying chamber, 235 cubic feet of air at 110° are necessary for the removal of one pound of water as vapor. These requirements are only illustrative; the values given above vary with individual products.

(b) *Humidity Effects*

Naturally, the drier the air when it enters the drying chamber the more moisture it will remove per unit volume. On the other hand, if the heated air is re-used there will be a considerable saving in heat because it requires about twice as much heat to heat fresh air as it does to heat once-used air.

In many fruits, if they are exposed to a low relative humidity and a high temperature, the moisture leaves the surface more rapidly than it can diffuse from the center and an almost impervious layer forms on the surface impeding the diffusion of the water and lowering the evaporation rate. This casehardening can be avoided by increasing the relative humidity of the drying air to such a point that drying does not take place too rapidly in the initial stages. Commercially, some air is recirculated and fresh air added to maintain the volume at a constant level, a practice resulting in a fuel saving of about 50%. For some fruits, especially pears and peaches, a relative humidity of 30 to 35% or higher is used.

(c) *Air Flow*

The velocity of the air through the drying chamber has a great effect on the rate of moisture removal: Air at a velocity of 230 feet per minute removes moisture twice as rapidly as still air; air traveling at 460 feet per minute removes moisture three times faster than still air. In commercial practice a velocity of 300 to 1000 feet per minute is generally used because higher air velocities result in a certain amount of back pressure, so the power necessary to operate the fan increases to such a point that it is no longer economical. The back pressure is developed as a result of the frictional resistance offered to the flow of air by the product, its container, and the drying chamber. It can be calculated that a certain fan operating at 350 revolutions per minute will deliver 23,600 cubic feet of air at 1 inch back pressure but only 14,700 cubic feet of air at 2 inches back pressure. Obviously the volume of air, and hence the pressure developed, are approximately proportional to the number of revolutions of the fan. The volume varies with the number of revolutions, the pressure with the square of the

revolutions, and the power to operate the fan with the cube of the revolutions. From this it may be seen that, for every blower system, there is a very definite optimum for efficient operation which must be determined specifically for that system.

Natural draft dehydrators (see page 95) are the simplest, but require more labor for loading and unloading. This type of apparatus takes advantage of the tendency for hot air to rise: Heated air is introduced at the bottom, flows up and around the product to be dried, and then out of the system. Usually the air is not recirculated in drying chambers using natural draft.

Forced air dehydrators utilize a fan to circulate hot air through the drying chamber. In this case it is very easy to recirculate all or any fraction of the air and also to provide a system over which the operator has complete control. Two systems of forced air drying are generally used: the parallel current for halved fruits or cubed and sliced products; and the countercurrent for whole fruits and most other products. The product to be processed governs the choice of drying method used regardless of the equipment chosen.

Parallel-Current Drying.—In this system, the product enters the drying chamber along with the hot air, and is discharged at the cooler end of the chamber. The advantage claimed for this system is that moisture is rapidly removed from the fruit at a time when it is in a condition to give its moisture up most readily. The fruit behaves somewhat as a wet bulb thermometer. Therefore, higher drying temperatures may be used, with the result that the rate of drying is increased. The drying fruit gradually approaches the region of lower temperature and higher humidity so that scorching and overdrying are minimized. Since the dried fruit leaves the drying chamber at a lower temperature there is considerably less heat loss than with the countercurrent system. There are two outstanding disadvantages: there is a tendency to caseharden the product by the high initial drying rate; and there is a greater loss of juice in the early stage of drying than in other procedures.

Countercurrent Drying.—In this system, the wet product enters at the air exhaust end of the drying chamber, and is discharged at the hot end of the chamber. The product is dried very slowly at first, in air of relatively high humidity. As the moisture is removed, the product is exposed to somewhat more vigorous drying conditions: the rate of drying is somewhat less; and there is considerable tendency for the fruit to become scorched and for the sugars to caramelize. A lower drying temperature must be used, with the result that a slower drying rate is obtained in the case of countercurrent drying than is possible in the parallel system.

(d) *Effect of Temperature*

The time required for drying depends upon the temperature of the air used for the drying operation. The economics involved require that the highest possible temperature must be used without exceeding the critical temperature (see Table 13) of the product being dried. At temperatures above this critical temperature, the practically dry product is likely to scorch, the sugars contained are likely to caramelize,

TABLE 13
CRITICAL TEMPERATURES FOR VARIOUS FOOD PRODUCTS

Product	Temp., ° F.	Product	Temp., ° F.
Apples.....	165	Parsnips	170
Apricots.....	160	Peaches	150
Bananas.....	165	Pears	150
Beets.....	170	Peas	145
Brussels sprouts.....	140	Peppers	145
Cabbage.....	145	Pimientos	145
Carrots.....	170	Potatoes, sweet	175
Cauliflower.....	140	Potatoes, white	150
Celery.....	140	Prunes	170
Cherries.....	170	Raspberries.....	170
Corn.....	150	Rhubarb.....	175
Figs.....	160	Spinach	175
Grapes.....	160	Strawberries	160
Horse-radish.....	145	Tomatoes.....	150
Okra.....	140	Turnips.....	170

ize, the color, flavor, and aroma of the product are likely to be adversely altered, and there may be serious losses resulting from dripping.

(e) *Heat Losses*

The heat loss through exhaust air amounts to about 25% of the total heat generated in the furnace; frequently this loss increases to even 50%. It may be reduced by recirculation of the air, but it cannot be eliminated entirely because of air leakage around doors, cracks, and similar vents in the drying chamber as well as losses through radiation. A certain loss occurs up the furnace or boiler stack, the amount of which is characteristic of the furnace design and does not concern us here.

(f) *Preparation of Product for Drying*

In general, food products are prepared for drying much in the same manner as they are prepared for canning and freezing, although some products are not peeled. In the case of vegetables, blanching prior to dehydration is necessary to destroy the enzyme systems responsible for the loss in color and flavor otherwise occurring during drying. Blanching usually intensifies and fixes the color. It also increases the rate of drying, and inhibits those changes which make the vegetables tough and difficult to cook. The quality of dehydrated tomatoes, onions, and peppers is not improved by blanching.

(g) *Fumigation*

In the case of dehydration of food products it is necessary to protect the product against insect damage by fumigation (see page 253). Sulfur dioxide is the most commonly used fumigant. Carbon disulfide has been used, but is very explosive and presents a fire hazard. Hydrogen cyanide gas is used to a limited extent, but

the fumes are extremely dangerous to the workmen and the product retains an appreciable amount of the gas after fumigation. Ethylene oxide is much safer than either of the above two. Chloropicrin is equally effective, but must be used with care since it is a lachrymator. A mixture of ethylene dichloride and carbon tetrachloride is a good nonexplosive, nonirritating fumigant. Methyl bromide is very effective, but also very toxic.

TABLE 14
FUMIGANTS AND THE AMOUNTS USED PER 1000 CUBIC FEET OF AIR SPACE

Fumigant	Amount	Comment
Carbon disulfide	20 pounds	Explosive, inflammable
Hydrogen cyanide	8 ounces	Very toxic to man, leaves residue
Methyl bromide	1 pound	Toxic to man
Ethylene dichloride—carbon tetrachloride	15 to 20 pounds	Anesthetic to man
Ethylene oxide—ethylene dichloride	10 to 15 pounds	Anesthetic to man
Ethyl formate	5 to 10 pounds	
Ethylene oxide	2 to 4 pounds	
Chloropicrin	1 pound	Lachrymator
Sulfur dioxide	Burning sulfur fumes	Inexpensive

Some products must be fumigated before and after drying, others after dehydration, and most before packaging. In the case of the liquid fumigants, a small quantity may be added directly to the packages before storage and shipping.

EQUIPMENT

(a) *Natural Draft Dehydrators*

This type of dehydrater is relatively simple in construction and operation and is the least expensive to build. It is inefficient in fuel consumption but is ideal where there is a sufficient quantity of waste heat available for recovery. The general design, as pointed out on page 93, consists of a drying chamber placed above a heat source so that the cold air enters the heating unit at the bottom, rises as it is heated, passes through the drying chamber over, around, and through the product to be dehydrated, and finally escapes from the system.

Kiln Drier.—This type is perhaps the oldest still being used commercially. It consists of two floors, the lower housing the heating mechanism, which may be air or steam. In the case of air, a furnace burning wood, coal, oil, or gas is connected to a series of large sheet-metal pipes immediately below the upper floor. These pipes, after completing a circuitous route under the floor, are connected to the stack. For steam, the pipes and radiators are installed just below the upper floor.

The upper floor, about 20 feet square, is the drying chamber. The product to be dried is placed on a hardwood floor, consisting of slats spaced about 0.25 inch apart, to a depth of 3 to 12 inches. A steep, four-sided roof fitted with a large ventilator

at the apex completes the machine. The product to be dried is turned by a fork or shovel during the drying operation.

Steam heating is preferable because it permits much greater control over the drying operation; and the installation of an exhaust fan in the ventilator greatly increases the drying rate. The apparatus, while more or less suited to the drying of hops, apples, and similar substances, is very unsatisfactory for the drying of soft fruits because of the damage caused by bruising.

Tower or Stack Drier.—This machine is composed of a room about 10 feet high, with a furnace located in the bottom. The flue gases follow large pipes in a circuitous route to the stack. Near the top of the room is a series of about 6 cabinets each holding about 12 trays, 3 feet square, on which is placed the product to be dried. The hot air rises through the product to be dried. As the material on the bottom tray becomes dry the tray is removed. All the other trays are shifted downward one step and the fresh product, on its tray, placed at the top of the pile. Care must be taken that the products being dried do not mat and impede the air flow too greatly.

Cabinet Drier.—This machine is an improvement over the tower or stack drier in that the heat is supplied by steam coils directly below each tray. Otherwise, the construction is similar to that of the stack drier. The drying is rapid, and the operator maintains excellent control over the operation at all times.

Oregon Tunnel Drier.—This drier has been in use for many years, and is similar in design to the kiln drier except that the drying tunnels rest on a floor 12 to 16 feet above the floor of the furnace room. Each tunnel is about 20 feet long, 5 feet high, and 3 feet wide. The whole tunnel slopes about 2 inches per foot. Each furnace unit serves 2 to 4 tunnels, the hot air entering through an opening about 3 feet in diameter at the lower end of each tunnel, and the amount of air entering each tunnel controlled by a slide valve. The product to be dried is placed on trays, which are placed on runways at the upper end of the tunnel. The dry fruit is removed from the lower end of each tunnel. The temperature differential between the upper and lower ends of the tunnel amounts to 30 to 50° F., indicating the high efficiency of this type of drier. It is not, however, as efficient as the forced air types.

Ceramic Oven Drier.—This apparatus is constructed of firebrick and masonry much in the same style as bread ovens, but the slow, uneven drying caused by inadequate circulation prevents it from being generally used. The product is placed on trays which are then put on trucks and the whole unit rolled into the oven until dry. The heat is radiated from the walls to the product being dried. Later designs with forced air and recirculation greatly increase the rate of drying, but this type is still not so good as other types.

(b) *Distillation Type Dehydrators*

This type consists of an apparatus similar in design to steam cookers. The moisture is driven from the product by heat and the evolved water condensed by suitable condensers. This type of dehydrater is not used extensively by the food industry.

(c) *Vacuum Dehydrater*

This machine consists of a heavy-walled, sheet-metal or cast-iron chamber equipped with steamheated shelves or steam coils on which the trays of material rest. The chamber is connected to a vacuum pump and a suitable condensing device. Such an apparatus requires less heat to operate than other types because practically all the heat is used in the evaporation of moisture. Vacuum dehydration permits the use of lower drying temperatures. It also minimizes oxidation, and thereby greatly reduces the tendency for fruits to darken. The equipment is expensive and has not found widespread use, but is employed in the production of powdered foods.

(d) *Forced-Draft Dehydraters*

Tunnel Dehydraters.—This has proved to be the most efficient type of drier. It produces a more uniform drying, is the least costly dehydrater to build and operate, and its operation permits a most rapid drying. It consists of a chamber longer than it is wide through which the trays of material travel on trucks moving progressively along the tunnel as the drying proceeds. The hot air enters at one end and is removed at the other. The air may be heated by steam radiators, electrically heated grids, or hot air pipes, or by mixture with the combustion products from the furnace. The electrical system is more expensive to build and operate but permits more exact regulation. Mixing of air with the products of combustion of gas, oil, or kerosene furnaces is most efficient, but there is danger of discoloration by soot in case of incomplete combustion. The air is circulated by one of the several types of blowers, *i. e.*, disk, multivane, propeller, and paddle-wheel types. The multivane and propeller types of fans are most commonly used. The air may be recirculated but care must be taken that the return air duct is large enough not to impede the flow of the air, so that back pressure is not excessive.

Belt Tunnel Dehydraters.—This type is very similar to the tunnel drier except that the product is conveyed on several woven, metal-cloth conveyors placed one above the other. The air is blown either lengthwise or crosswise in the tunnel. The main disadvantage of the belt tunnel drier is that the drying area is much less than in tray driers.

Cabinet Dehydraters.—These are similar to the cabinet driers described on page 96, except that the air is delivered between each pair of trays by a tuyère and the direction of air flow is frequently reversed to insure more uniform drying at all points of the tray. This drier is very complicated, a factor which does not adapt itself well to commercial operation.

(e) *Spray Driers*

Milk, sirups, and certain fruit juices can be forced into a large chamber in the form of a fine spray against a current of heated air and the resulting powder recovered in an air-settling chamber or in bag filters beyond the drying chamber.

In another type of machine, the drying chamber consists of an inverted cone surrounded by a large cylinder constructed of sheet metal and into which the air heated by steam coils is forced tangentially by a powerful fan giving it a cyclonic motion within the chamber. The liquid to be dried is sprayed by a nozzle into the center of the cyclone, whereupon the droplets travel outward under centrifugal force, meeting air of increasing temperature and decreasing humidity. Upon reaching the walls of the chamber, the droplets have been dried to a powder and settle to the conical bottom of the chamber.

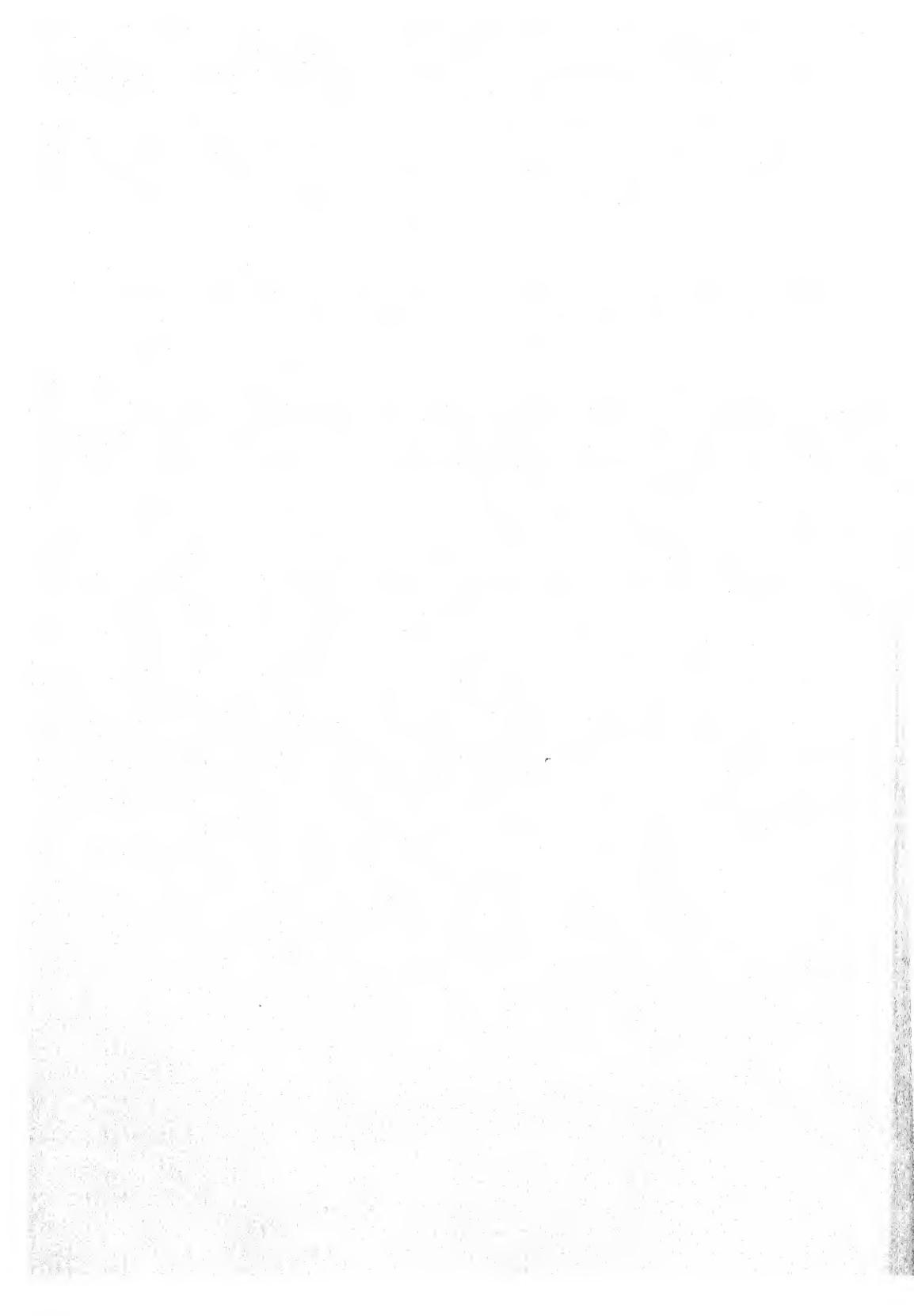
Many juices must be mixed with lactose, sucrose, or dextrose during drying because the juice may melt at the drying temperatures and upon cooling become a solid, glasslike product which is very hygroscopic and which may revert to a sirup within a few hours' exposure to air. Grape juice, for example, has been found to melt between 130 and 240° F.

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PART IV

SANITARY AND QUALITY CONTROL



Chapter III

FOOD SUPERVISION BY GOVERNMENT AGENCIES

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Government agencies which supervise food have many objectives. These agencies protect the public health, prevent fraud, promote new industries, or small groups in industries, promote local trade groups and domestic industries, prevent unfair competitive trade practices, assist in the conservation of game and wildlife, and carry on research to solve problems of production, preservation, storage, and other aspects of food handling. In some cases, an agency has a single function; in other cases, a particular agency may have several functions. An agency may carry out more than one function in order to obtain a single main objective. An example of this is the New York State Conservation Department which has as its chief function the conservation of game and the fostering of home industries connected with certain wildlife. These aims are accomplished in part by enforcing sanitary and bacteriological standards for oysters and clams. Another example is the Office of Price Administration, which was organized to regulate prices and thus prevent inflation. In carrying out this function, the O. P. A. has controlled the sale of contaminated and adulterated food.

Thus, there is considerable complexity caused by such duality of purpose and approach. In addition, great complexity occurs because food control agencies have overlapping jurisdictions. There are federal agencies controlling food which crosses State borders, or which leaves or enters the country; State agencies which control food throughout or in parts of their own States, and often in neighboring States as well; city agencies which control the food supply under their own jurisdiction and within the city, and inspect sources in other cities in the State, or even in other States; and county agencies which supervise food in their own counties, which may include towns and cities, and which also duplicate inspection, although, because of their size, to a much lesser degree.

The type, degree, and quality of food supervision is further complicated by natural modifying factors such as the limitation of scientific knowledge available to solve problems of food control, and the relative emphasis placed on some aspects of food control as compared with others. In the City of New York, considerable emphasis is placed upon shellfish control, whereas, throughout the rest of that State, very few investigations of the shellfish offered for sale are made. In the State of New York,

there is a considerable interest and activity in the problem of trichinosis, an activity which is almost entirely absent in most other States.

All this has led to an undesirable situation which warrants study and revision. Duplication of inspection occurs in abundance; laws and regulations of different departments governing the same subject vary even in the same locality and many laws are on the books where fewer would lend themselves to greater understanding and more effective enforcement. Trade barriers between cities in a State and between neighboring States have been built up. In many localities, an industry will receive considerable inspection whereas the same industry in a neighboring locality may receive much less or no attention at all.

Styles of food control by public health agencies have changed with the change in attitudes toward potential disease hazards. Many food frauds have been acknowledged as having no public health significance. Nevertheless, as a result of historic development, and perhaps because of the absence of other effective enforcement agencies, health departments continue to engage in the prevention of food frauds. In many cases, it is extremely impractical to separate fraud control from the public health control of the same food. On the other hand, one finds departments of agriculture or markets, which control foods from a public health point of view, in addition to controlling frauds and other economic aspects. Great forward steps have been taken and large advances have been made. Much clarification and re-evaluation of basic administrative principles in food control remain to be accomplished.

I. FEDERAL AGENCIES

The federal agencies which have supervision over food are:

1. Federal Security Agency
 - (a) United States Public Health Service
 - (b) Food and Drug Administration
2. Department of Agriculture—War Food Administration
 - (a) Food Distribution Administration—Office of Distribution
Meat Inspection Division, Livestock and Meats Division
Marketing Administration
 - (b) Agricultural Research Administration
Bureau of Animal Industry
Bureau of Agricultural and Industrial Chemistry
Bureau of Dairy Industry
Bureau of Plant Industry, Soils and Agricultural Engineering
Bureau of Entomology and Plant Quarantine
Bureau of Human Nutrition and Home Economics
Office of Experiment Stations
Beltsville Research Center
 - (c) Bureau of Agricultural Economics
3. Treasury Department
 - (a) Bureau of Internal Revenue
4. Department of Interior
 - (a) Fish and Wildlife Service

5. Interstate Commerce Commission
6. Federal Trade Commission

In addition, there are military agencies and emergency war agencies which control foods. These are:

7. Military food control agencies:
 - (a) War Department Office of the Surgeon General
Veterinary Division
 - (b) Department of the Navy
Bureau of Medicine and Surgery
8. Emergency war agencies:
 - (a) Office for Emergency Management
War Production Board
Office of Price Administration
Office of War Mobilization
 - (b) Combined Food Board United States and United Kingdom
 - (c) Office of Coordinator of Fisheries, Department of the Interior

1. Federal Security Agency

(a) *The United States Public Health Service*

In addition to its many other important health functions, this agency participates in the supervision over certain foods. Actual, direct food supervision is given by the United States Public Health Service to milk and water which are consumed on interstate carriers. It also participates in the control of shellfish. Since the examination of the ready-to-use milk, water, and shellfish tells only a small part of what has to be known about their sanitary qualities and freedom from contamination, the sources of supply are investigated by the Service.

Milk Control.—In its milk control work, the Public Health Service acts in the dual capacity of adviser to the States, and supervisor of milk used on interstate carriers. Field consultation services are furnished to many States by Public Health Service milk specialists. State-wide milk sanitation surveys are conducted and assistance is given in the organization of State and local milk sanitation programs and the training of personnel. In 1924 the Public Health Service formulated and published a *Standard Milk Ordinance* which has been revised from time to time. In 1927 it was revised to a milk ordinance and code. This model ordinance achieved outstanding results in securing interest in, and attention to, milk sanitation. By the end of 1942, the *Standard Milk Ordinance* was adopted by 109 counties and 851 cities located in 34 states. In addition, one State adopted this recommended milk ordinance for inclusion in the health department regulations applicable throughout the State. The Public Health Service semiannually publishes lists of communities which have attained a rating of 90% or more compliance with the requirements of the *Standard Milk Ordinance*.

Shellfish Control.—The work of the Public Health Service on shellfish control problems has been especially beneficial to the States. The Service cooperates with

the States in the investigations of the efficacy of sanitation practices relating to the production and handling of shellfish. Growing areas and shucking and packing plants are subjected to sanitary surveys and bacteriological examination. As of July, 1941, endorsement was given to 1878 certificates issued by State health departments. Dealers certified by the Public Health Service were listed by States and the lists were distributed to health officials of the United States and Canada. The requirements under which State shippers are certified are known as "U. S. Public Health Service Minimum Requirements for Endorsement of State Shellfish Control Measures and Certifications for Shippers in Interstate Commerce." The Service has conducted many research projects on shellfish with various States.

Water Control.—In 1914 the Public Health Service adopted bacteriological standards for water for drinking and culinary use on interstate carriers. These standards were further revised in 1925 and in 1942, when chemical standards and requirements regarding source and protection were included. An accompanying manual of recommended water sanitation practice was also issued in 1943. Since 1914, a procedure of certification of water supplies used by interstate carriers has been in effect through the cooperation of State health departments and the United States Public Health Service. Although the standards of the Public Health Service had legal application only to water used on interstate carriers, in practice these were applied by local and State agencies in judging the quality of all public water supplies. The standards therefore had tremendous influence in advancing water supply sanitation.

Restaurant Ordinance.—In June, 1940, the Public Health Service issued a *Restaurant Sanitation Code and Ordinance* recommended for voluntary local adoption; and by July, 1941, reports indicated that it was in effect in many communities and defense areas in at least 17 States, including five in which it had State-wide application. This recommended *Ordinance and Code Regulating Eating and Drinking Establishments* was revised and reissued in 1943.

Frozen Desserts Ordinance.—There is also available a model *Frozen Desserts Ordinance and Code* (May, 1940) prepared and recommended by the Public Health Service.

Rodent Elimination.—The work of the Public Health Service in rodent elimination is noteworthy. This work started in connection with the ratproofing of vessels. General instructions are available for the ratproofing of ships.¹ A model ratproofing ordinance relating to food factories and other buildings has been prepared by the Public Health Service and can be found in the Service publication, *The Rat and Ratproof Construction of Buildings*.² See pages 267 *et seq.*

Trichinosis Control.—In 1941 the *United States Interstate Quarantine Regulations* of the Public Health Service were amended to require that all garbage shipped in interstate commerce be heated to a temperature of 212° F. for 30 minutes before being used for feeding swine. Enactment of a similar regulation by the States and

¹ S. B. Grubbs and B. E. Holsendorf, U. S. Pub. Health Service, *Suppl.* 93 (1931).

² B. E. Holsendorf, U. S. Pub. Health Service, *Suppl.* 131 (1937).

enforcement of this regulation throughout the country will do much to solve the problem of trichinosis.

Land and Air Conveyances.—In 1942 the Public Health Service adopted and promulgated a *Sanitation Manual for Land and Air Conveyances Operating in Interstate Traffic*. This manual is intended for use in the administration of interstate quarantine regulations as they relate to sanitation of water supplies, milk and milk products, eating and drinking facilities, excreta disposal, and other items of sanitation concerned with railroad cars, motor vehicles, and airplanes engaged in interstate traffic. It also was designed to provide public health agencies and carriers with the necessary information upon which to base inspection and control procedures.

Disease Outbreak Statistics.—Another service performed by the Public Health Service has been the compilation of outbreaks of disease assembled from reports by State health departments. In 1939 this compilation was extended to include not only milk-borne outbreaks, but also those traced to water and food products in general. The 1939 compilation showed 43 of the 249 outbreaks to have been traced to water supplies, 41 to milk and milk products, 148 to other foods, and 17 to unidentified vehicles of transmission.

Liaison Activities.—Since the outbreak of the second World War, the Public Health Service has performed liaison and reconnaissance activities. A Public Health Service officer has been detailed to each of the nine Army Corps Areas to serve as liaison officer between the Service and the Army, Navy, and civilian health authorities on all health and sanitation matters pertaining to defense. Consultation services are furnished on water, milk, and food supplies.

States Relations Division.—The States Relations Division, which supervises the activities outlined above, was formed in 1944. This was formerly the Division of Domestic Quarantine, and was at first concerned with preventing interstate spread of communicable disease by the application of quarantine restrictions. It was soon apparent that the spread of disease could be most effectively prevented by assisting State health authorities to control communicable illness at the source. Accordingly, major emphasis was shifted from quarantine procedure to aid the States in developing adequate State and local health organizations. With the passage of the Social Security Act in 1935, federal funds were made available to States and municipalities for augmenting health facilities. Sanitary engineering personnel were engaged in safeguarding water, milk, and shellfish supplies, and in various environmental sanitation activities throughout the States and in individual communities.

(b) Food and Drug Administration

Actual direct food control is given by the Food and Drug Administration to any and every food except meats inspected by the Meat Inspection Division (page 110), moving in interstate commerce which may require its attention. Normally, the Administration does not perform bacteriological examinations of fluid milk and shellfish, nor does it investigate the source of supply of these products. It does,

however, supervise many milk products such as evaporated milk and milk powder, and may also investigate adulteration of shellfish. In the case of those foods which it does control, it examines the foods and investigates the source of supply as well, in an attempt to secure as complete a picture as possible of the sanitary condition and possibilities of adulteration of each food product.

Function and Personnel.—The function of the Food and Drug Administration is the enforcement of laws designed to secure freedom from adulteration, and to insure the purity and wholesomeness of foods (and drugs, devices, and cosmetics). These laws are five in number, namely: Food, Drug, and Cosmetic Act of 1938; Tea Act; Import Milk Act; Filled Milk Act; and Caustic Poison Act.

The staff of the Food and Drug Administration normally numbers about 900, divided into a field service of 600 persons and a staff in Washington of 300. The personnel includes chemists, bacteriologists, physicians, veterinarians, microscopists, pharmacologists, inspectors, administrative officers, and other specialists. The field service is made up of three inspection districts: eastern (the Atlantic seaboard); central (the Mississippi Valley); and western (the Rocky Mountains and Pacific Slope areas). There are sixteen inspection stations in the three districts. The station headquarters are manned by inspectors and analysts working under the direction of a station chief. This organization is flexible and the operations can be readily shifted from routine law enforcement to cope with an emergency such as the contamination and spoilage of foods by flood, or the discovery that a poisonous food has been widely distributed. The stations operate under the general direction of the district chief, and district officers are in turn under the general direction of Washington headquarters.

Divisions.—The Food and Drug Administration is made up of the following four main divisions:

1. Administrative:

(a) *Interstate Division*—aids in determining administrative policy; suggests basic investigations; receives and evaluates field reports; possesses the power of final decision (subject to the approval of the Commissioner) with respect to charges to be brought and action to be taken.

(b) *Import Division*—is responsible for the enforcement of the Tea Act, the Import Milk Act, and the import section of the Food, Drug, and Cosmetic Act.

2. Subject Matter:

(a) *Food Division*—acts as reviewing laboratory on cases developed under the food provisions of the several acts and furnishes expert witnesses for court cases; prepares project plans on foods and work which is necessary preliminary to regulatory activity. In such investigations, this division, with the assistance of the field force, ascertains current trade practices through the medium of factory inspections, prepares and subsequently analyzes experimental packs of food products, determines the composition of numerous market samples, and acquires information concerning consumer understanding of the composition of foods and various trade terms. Special investigations are made in connection with the formulation of food standards. This division also must supply the information essential to the formulation of appropriate food regulations.

(b) *Drug Division*

(c) *Cosmetic Division*—in addition to its other activities, performs the necessary work for color certification.

3. Specialized Technical:

(a) *Vitamin Division*—is responsible for determining the validity of vitamin claims on products; analyzes samples; conducts research; provides court testimony.

(b) *Bacteriological Division*—aids in determining the likelihood of danger to health through the transmission of harmful germs; aids in detecting decomposition in foods and in ascertaining the presence of other filth such as sewage pollution. This division is also responsible for projects involving sea foods, whether or not such projects have bacteriological phases.

(c) *Division of Pharmacology*—in addition to its drug work, makes toxicological investigations to determine whether certain substances found in foods or their containers are poisonous or deleterious.

(d) *Microanalytical Division*—is responsible for the microscopical identification of component ingredients of mixtures, as well as the detection of decomposition and filth in foods, drugs, and cosmetics. Microscopical methods have been devised for the detection of spoilage and filth in foods such as tomato products, cereal and dairy products, confectionery, and dried fruits.

4. Division of State Cooperation—develops and maintains active cooperation with State and local officials enforcing State and local food and drug laws.

Enforcement.—*The Food, Drug, and Cosmetic Act of 1938.*—It is apparent that the facilities of the Food and Drug Administration do not permit a complete coverage of all products and industries within the jurisdiction of the Food, Drug, and Cosmetic Act. Selective enforcement, therefore, is necessary, and a project plan based upon the following principle is the basic mode of operation.

Coupled with the segregation of types of violations is a segregation of products and manufacturers most commonly found to violate the law. This is accomplished by obtaining as complete a knowledge as possible of the practices of every branch of the industry and thus making possible the detection of probable violations as well as the determination of the identification of manufacturers whose operations are likely to require supervision. Actual enforcement is accomplished by educational efforts, public hearings, written notices, and warnings to control minor violations. Advisory legal interpretations and valuable technical information are also given to permit a ready compliance with the law. In addition to these informal methods of enforcement, there are the more formal methods of seizure, criminal prosecution, and injunction.

In *seizure* (known legally as a libel for condemnation proceeding) the article in question is seized by a United States marshal (usually accompanied by a Food and Drug Administration inspector) who acts upon a court warrant issued pursuant to the filing of a libel by a United States attorney with the proper federal court. The seized merchandise then is within the jurisdiction of the court. The party who would usually seek its release (claimant) may fail to make an appearance before the court, in which event the case is disposed of on default, or he may appear but agree with the contentions of the Administration in the libel, in which event a consent decree would ensue. When the claimant contests the seizure, the question of whether or not the articles are in violation of the act is tried in federal court. Seizure is employed against products containing ingredients harmful to health and those marred by filth and decomposition. However, products which have been seized and condemned are not necessarily destroyed; but they also may not be disposed of contrary to the provisions of the Food, Drug, and Cosmetic Act or the laws of any State or Territory in which

the disposition happens to take place. The court may order the offending products destroyed if they cannot be reclaimed in any way, which is true of decomposed foods and foods containing poisonous substances. But frequently adequate reworking (for example, the removal of excess moisture from butter), sorting (often possible with canned goods not all of which have been damaged), or cleaning (appropriate for the separation of excessive debris from nuts) will eliminate the federal charge of adulteration. In the same way, relabeling (for such violations as an incorrect statement of net weight) will often render misbranded articles entirely legal and suitable for distribution. Under these circumstances, the articles may be released to their owner under bond for reconditioning under governmental supervision. Seizure is used also to prevent the distribution of products containing grossly false or misleading claims, and those so adulterated or misbranded as to demoralize legitimate trade practices seriously. When an adverse decision against a claimant has been rendered, or when an owner has abandoned goods which have been seized, the court, as alternatives to destruction, may either give them outright to charity, or direct their sale by the appropriate United States marshal after ordering him first to eliminate the adulteration or misbranding involved. The proceeds of the sale, less the legal costs incurred, are sent to the United States Treasury.

As stated, another possible penalty is *criminal prosecution* of the person or firm responsible for the violation of the provisions of the act. For the commission of any of the deeds prohibited by law, the maximum fine is \$10,000 and the maximum imprisonment three years. Unlike seizures, which occur wherever a consignment happens to be found, criminal prosecution is always confined to the jurisdiction in which the defendant has his place of business. It is a slow remedy because the act requires that a potential defendant be first given appropriate notice and an opportunity to present his oral, or written views on the matter, after which proper pleadings must be drawn up, affidavits of an analyst and other witnesses secured, and all forwarded, through the Department of Justice, to the local United States attorney. The case must then await its turn on the court calendar. The trial itself is subject to the legal restrictions prevailing in criminal procedure, one of which requires exact evidence to prove guilt. The result is that, though criminal prosecution may legally be based upon the same consignment which led to the institution of seizure proceedings, such prosecution is often precluded even though seizure action can be maintained. This is true, for example, of perishable foods subject to seizure because decomposition occurred after shipment. In such cases, no criminal responsibility ordinarily rests upon the manufacturer.

In some instances, seizure and criminal prosecution are unsatisfactory means of enforcement, especially where a person or firm indulges in repeated and frequent violations. Congress has therefore authorized the enforcing agency to apply to federal district courts for restraining orders (*injunctions*) which in effect deny the channels of interstate commerce to adulterated or misbranded foods, and to unlicensed new foods in violation of the conditions of an emergency permit.

During 1942, 70% of the field time of the Food and Drug Administration spent in

the enforcement of the Food, Drug, and Cosmetic Act was devoted to food control, and another 5.4% to food-standards work.

The Import Milk Act.—The Import Milk Act was enacted in 1927. Today Canada is our only source of foreign fluid milk and cream coming within the scope of the act, which applies only to fluid milk and not to dried, condensed, and evaporated products. Permits are required of importers or shippers and are issued on a twelve-month basis, revocable in case of violations, with the additional possibility of fines and imprisonment.

Fluid milk and cream are held unfit for importation when all animals producing such products are not healthy, particular tests being administered to insure freedom from tuberculosis. The producing farms must be declared sanitary in accordance with a scoring system and the temperature and bacterial counts must not exceed specified limits. These requirements have tended to eliminate the importation of products which have not been pasteurized.

The Filled Milk Act.—The Filled Milk Act, enacted in 1923, prohibits the manufacture or sale within federal jurisdiction of any combination of milk, cream, or skimmed milk with any fat or oil other than milk fat, so that the resulting product will resemble or imitate milk, cream, or skimmed milk in any form. Such a product, according to the act, is an adulterated article of food the sale of which is a fraud upon the public. Enforcement is solely by means of criminal prosecution, since the Filled Milk Act contains no provision for seizure or injunction.

The Tea Act.—The Tea Act (passed in 1883) forbids the entry into the United States of any tea which fails to meet the standards of quality, purity, and fitness for consumption established by the Government.

Under the provisions of the Tea Act, a board of seven tea experts, appointed each year by the Federal Security Administrator, fixes uniform standards of quality, purity, and fitness for consumption for teas to be imported into the United States. Samples of these standards are sold at cost to importers, who send them to their agents in the Far East, and similar samples are placed in the hands of the examiners at the ports of Boston, New York, San Francisco, and Seattle.

Under the law, an importer may appeal within thirty days to the Board of Tea Appeals when he is of the opinion that a shipment of tea has been unfairly rejected. There is no appeal from the decision of this board, which is made up of three members of the Federal Security Agency. He is allowed six months in which to remove his rejected tea from the country, and failure to do so results in the shipment's being destroyed.

2. Department of Agriculture

The exigencies of the second World War caused deep-seated changes in the organization of the Department of Agriculture. These changes were designed to combine various functions of the different bureaus of the department in such a manner as to obtain maximum effect for the war effort. The reader should note carefully the functions which are described in the following sections rather than the names of the

bureaus carrying them out, for it is likely that further administrative and organizational changes will take place in which the names of the bureaus exercising certain functions will change while the functions themselves will suffer little alteration.

During the wartime emergency period, the line agencies of the Department of Agriculture have been divided into two administrative units. The agencies, in one, the *War Food Administration*, are responsible to the War Food Administrator. The War Food Administrator is appointed by and directly responsible to the President. The other agencies—Agricultural Research Administration, Farm Credit Administration, Rural Electrification Administration, and Forest Service—are responsible to the Secretary of Agriculture. We are concerned primarily with the Food Distribution Administration of the War Food Administration and with the Agricultural Research Administration.

During March, 1943, the Food Production Administration, the Food Distribution Administration, the Commodity Credit Corporation, and the Extension Service were consolidated into the Administration of Food Production and Distribution. The name of the consolidated organization was changed in April, 1943, to the War Food Administration. This agency was created within the frame of reference of the Department of Agriculture but not as a line agency of the latter, since the War Food Administrator is responsible to the President and not to the Secretary of Agriculture. The functions this agency exercises which affect the control of foods will be discussed in the section concerning its subdivision, the Food Distribution Administration.

(a) *Food Distribution Administration—Office of Distribution*

This administration was established within the Department of Agriculture on December 5, 1942. It combines the work formerly carried on by the Agricultural Marketing Administration, the Sugar Agency, functions of the Office of Agricultural War Relations concerned with the distribution of food, the regulatory work of the Bureau of Animal Industry, and the Food Division and other food units of the War Production Board. In 1944, these functions were performed by the Office of Distribution.

Meat Inspection Division, Livestock and Meats Division.—Actual direct food control is given by the Meat Inspection Division (see Volume I, page 441) in peacetime only to meat and meat products which move in interstate commerce. Examinations of the product take place at stockyards and slaughterhouses, and at food processing plants, for which strict sanitary requirements are set. This agency enforces the Meat Inspection Act of June 30, 1906, amended March 4, 1907, and June 29, 1938, which provides for the inspection and labeling of meat and meat food products. In addition to enforcing the Meat Inspection Act, the Division also enforces the Horse-Meat Act of 1919, and the Import Meat Act of 1913. The work of this agency begins with prevention of disease in livestock. To do this, the Bureau of Animal Industry enforces federal and State quarantines in which dangerous, infectious diseases are confined within the smallest possible area and held there by quarantine restrictions until the disease is under control. The work of the division is nation-wide in scope.

Where possible, disease in animals is attacked within the States, generally on a long-time basis. The specific measures used in controlling epizootics depend on the findings of bacteriologists, veterinarians, parasitologists, and chemists. Veterinary supervision is provided at the public stockyards where each year, 60 to 70 million animals are assembled for slaughter or reshipment. The stockyards force supervises the disinfection of premises and equipment, as well as the dipping, testing, and immunizing of animals. The Bureau of Animal Industry also enforces the 28-hour law. This federal law prescribes a rest and watering period for animals being moved or held in transit for 28 hours or more, because of effects upon the health of the animal and its susceptibility to disease.

Under the 1907 act, cattle, swine, sheep, or goats which show signs of disease must be set aside and slaughtered separately, after which the carcass must be subjected to a careful examination in accordance with specific regulations.

Besides this *ante mortem* inspection, a *post mortem* examination of carcasses is made. This examination takes place at the slaughtering, meat canning, rendering, or similar establishment, in any State, Territory, or the District of Columbia. The carcasses and parts of all animals found to be wholesome and fit for human food are marked "Inspected and Passed" and, since March 5, 1943, with the letter "P" and an assigned permit number, or instead of the permit number with the assigned establishment designation. The carcasses of animals found to be unfit for food purposes must be marked "Inspected and Condemned" and destroyed in the presence of an inspector. Meat food products are also subject to strict inspection. During the fiscal year 1942 (*i. e.*, ending in July), inspection of cattle, sheep, swine, goats, and a small number of horses, and meat products from the foregoing species was conducted at 697 establishments in 264 cities and towns.

If the operation of a slaughterhouse or preserving establishment fails to comply with the requirements in connection with disposal of unsound carcasses or meats, the Department may withdraw its inspectors and the slaughterhouse loses its privilege of having its products stamped "United States Government Inspected and Passed" and then cannot ship in interstate commerce. During the fiscal year 1942, inspection service was initiated at 30 establishments and was withdrawn from 20.

In addition to its examination of carcasses of animals and meat, the inspectors in the "Government Inspected Houses" also control the sanitary aspects of the stockyards and establishments in which animals are handled or slaughtered.

During the fiscal year 1942, *ante mortem* and *post mortem* inspections were performed on more than 86,000,000 cattle, calves, sheep and lambs, goats, swine, and horses. More than 12,000,000,000 pounds of meat and meat food products were prepared or processed under supervision of the Division during the year. In addition to this work, the Division inspected meat and meat food products for conformance to specifications for other government agencies and issued certificates of exemption to retail butchers who deal on an interstate basis in meat of animals slaughtered by farmers on farms. The Division's seven meat inspection laboratories, maintained in different parts of the country, made chemical analyses and examinations of 30,310

samples of meat, meat food products, and the ingredients and substances used in their preparation. Approval was given to more than 41,000 new labels for use at inspected establishments and 154 for use on foreign meat and meat food products intended for importation. During the year, 840 sets of drawings and specifications for new and remodeled buildings and for installations of equipment for conducting meat inspection were submitted for approval. These were examined primarily to see that:

- (1) the proposed construction was of a type that facilitates sanitary maintenance,
- (2) the equipment was of a suitable type and was so arranged that operations could be conducted in a clean and otherwise acceptable manner, and
- (3) the facilities provided were suitable for efficient inspection.

The results of these activities for many years have been gratifying. The division reported in 1942:

"Most of the communicable diseases of food animals are under control, and campaigns for the complete eradication of several dangerous maladies are well advanced. The eradication of cattle ticks is more than 99% complete; the drive against bovine tuberculosis is in the mopping-up stage; excellent progress is being made against brucellosis. At the end of the year (1942), 549 counties in 24 States were practically free of brucellosis."

However, in 1942, only 60% of meat was federally inspected. This left and leaves a rather large gap in meat inspection. Also the problem of illness arising from the ingestion of inadequately processed trichinous meat and improperly cured hams and tongues to which staphylococcus food poisoning has been attributed, has not been overcome.

Under federal meat inspection laws, jurisdiction of the Meat Inspection Division is limited to commerce between the States, with foreign nations, and with possessions of the United States, and of the District of Columbia, and therefore does not apply to commerce solely within a State. However, in 1942, Congress by joint resolution authorized the Secretary of Agriculture to provide federal meat inspection during the war emergency to meat-packing establishments engaged in intrastate commerce, in order to facilitate the purchase of meat and meat products by federal agencies.

Marketing Administration.—The Agricultural Marketing Administration was established as an over-all marketing agency on February 23, 1942. Under an Administrator of Markets was consolidated the work formerly carried on by the Surplus Marketing Administration, the Agricultural Marketing Service, and the Commodity Exchange Administration. In the same month, the Consumers' Counsel Division was also made a part of the Agricultural Marketing Administration. This Division provides special services on consumer aspects of the planning and execution of the farm program and publishes *Consumers' Guide*. As noted on page 110, this agency was incorporated into the Food Distribution Administration.

The functions of the marketing administration may be grouped into four categories: market expansion programs; market stabilization programs; marketing services; and marketing regulation. These activities are designed to further the war effort, to encourage increased domestic distribution and consumption of farm products, to eliminate drastic fluctuations of market prices, to facilitate the movement of agri-

cultural commodities through distributive channels, and to eliminate, as far as possible, abuses and malpractices in marketing.

Market Expansion.—The market expansion program has employed such measures as direct purchase of farm products for distribution to needy families through State welfare agencies, the school lunch program and the penny-milk program; distribution of designated agricultural commodities through normal trade channels to public-aid families under the Food Stamp Plan; distribution of seasonal surpluses of perishables through normal trade channels under the victory food special program; diversion of farm products from normal trade channels to by-product uses; and encouragement of new outlets and new uses.

Market Stabilization.—The marketing stabilization programs are designed to stabilize and improve marketing conditions for agricultural commodities and to increase returns to producers. The programs operate through marketing agreements and orders issued under a democratic procedure which requires their consideration at public hearings and provides for referendums among producers and for the assent of handlers. Marketing agreements may be used for any agricultural commodity. Orders which make the terms of agreements applicable to all handlers may be issued only for specific commodities. These are: milk and its products, all fresh vegetables, fresh fruits (in the case of apples, only those produced in Washington, Oregon, and Idaho). Olives and asparagus for canning, tobacco, pecans, walnuts, soybeans, naval stores, package bees and queens, and hops. The marketing agreement programs for milk usually establish minimum prices to be paid producers and are administered in the New York area, for example, by a Federal Market Milk Administrator and the New York State Department of Agriculture and Markets. The programs for such commodities as fruits and vegetables usually provide for regulating shipments from producing areas on the basis of volume, grade, or size so as to adjust supplies more nearly in line with market requirements. The marketing agreement programs make it possible for producers to secure greater stability in the marketing of their products.

Marketing Services.—The Food Distribution Administration conducts a nation-wide market news service as well as inspection and grading services. It is responsible for all action programs dealing with the physical distribution and handling of farm products between the farmer and the consumer, including transportation, storage, processing, standardization, market organization, and marketing facilities.

Current information is gathered and disseminated on the market supply-and-demand conditions, movement, quality, and prices of livestock, meats, wool, fruits, vegetables, dairy and poultry products, grain, hay, feed, cotton and cottonseed, tobacco, rice, honey, and other farm products. The information is obtained at the large terminal markets, which are connected by a leased-wire system, and also at important receiving centers and shipping points. It is sent to producing districts throughout the country by wire, radio, newspapers, and mail.

Official standards have been formulated for nearly all farm products including a number of processed foods. In most cases, the use of official standards is voluntary;

in a few cases, their use is mandatory, such as when grain, cotton, and meat are shipped by grade in foreign or interstate commerce.

An inspection service is available in many of the principal producing areas and receiving centers for fruits and vegetables, hay, beans, grain, tobacco, and other products. A permissive grading service is available on dairy and poultry products, rice, and canned fruits and vegetables. See pages 151 *et seq.* Huge quantities of food purchased for branches of the armed forces and for domestic distribution to families receiving public aid, for free school lunches, for shipment by the Red Cross, and for transfer to other countries under the Lend-Lease Act are inspected.

Research is conducted on the standardization, classification, grading, preparation for market, handling, storage, and other phases of the marketing of farm and food products. Extensive research in the laboratory and in the field deals with problems concerning grading and the grade factors that make for variations in quality of farm products.

Marketing Regulation.—A large number of market service and regulatory statutes are administered by the Food Distribution Administration. The regulatory laws are the Commodity Exchange Act, the Perishable Agricultural Commodities Act, the Produce Agency Act, the Packers and Stockyards Act, the Standard Container Act, and the Federal Seed Act. Food service statutes include the Peanut Statistics Act and the Warehouse Act. Food standardization laws are the Grain Standards Act and the Export Apple and Pear Act.

(b) Agricultural Research Administration

In the reorganization of the Department of Agriculture carried out in December, 1941, the scientific bureaus of the department were consolidated into the Agricultural Research Administration. Under this agency are grouped the Bureau of Animal Industry, Bureau of Dairy Industry, Bureau of Plant Industry, Soils and Agricultural Engineering, Bureau of Entomology and Plant Quarantine, Bureau of Human Nutrition and Home Economics, Office of Experiment Stations, and the Beltsville Research Center.

Bureau of Animal Industry.—The Bureau of Animal Industry is primarily concerned with the protection and development of the livestock and meat industries of the United States. It conducts scientific investigations of the cause, prevention, and treatment of diseases and parasites of domestic animals, investigates the existence of such maladies, and directs or aids in their control or eradication. It conducts investigations and experiments in the breeding and feeding of domestic animals including poultry and studies methods of improving the quality and usefulness of their products. It also supervises a plan for improving the production and breeding qualities of poultry and reducing the mortality from pullorum disease. It administers the Animal Quarantine Act, the Diseased Animal Transportation Acts, and the Virus-Serum-Toxin Act.

Bureau of Agricultural and Industrial Chemistry.—This bureau conducts chemical and technological research for the advancement of agriculture, including adminis-

tration of the four Regional Research Laboratories established to develop new and broader industrial outlets for agricultural products, and conducts research relating to new and improved methods of rubber recovery from guayule and other suitable plants.

Bureau of Dairy Industry.—This bureau, established in 1924, not only has police power but conducts important investigations such as those relating to the breeding and management of dairy cattle, nutrition, and the physiology of reproduction and of milk secretion. It also records the production of cows in associations for the improvement of dairy herds in order to identify animals possessing inheritance characteristics which may be useful in transmitting to their progeny superiority in the ability to produce milk and butterfat.

It develops sanitary methods of handling milk on the farm, in transit, and in dairy plants, and studies the efficiency of dairy plant equipment, arrangement, and operation, and other factors affecting the commercial value of milk. It investigates the bacteriology and chemistry of milk and its products, as well as problems in the manufacture of milk products and by-products, and administers the Renovated Butter Act.

Bureau of Plant Industry, Soils and Agricultural Engineering.—The Bureau of Plant Industry was organized in 1902 to investigate soils, fertilizers, and plants, principally those of economic importance. Most of its work is conducted in co-operation with State agricultural experiment stations. Soil investigations center around the relationship between the soil and crops that grow in it. Research with plants is concerned chiefly with reducing the hazards of production and improving the quality of all crops. Other important work with plants includes studies of weed control and of methods of planting, harvesting, transporting, and storing crop plants.

This bureau is also a research organization engaged in investigations in the fields of chemistry, physics, engineering, and other physical sciences, with the object of gaining fundamental scientific knowledge relating to agriculture, improving agricultural methods and equipment, and developing new and wider industrial uses for agricultural products. Interest in agricultural chemistry and engineering is the result of developments that began with the appointment of a chemist to the Department of Agriculture in 1862.

Bureau of Entomology and Plant Quarantine.—This bureau was created by an organizational merger in 1935. In its study of insects, the Bureau investigates their life history and habits, especially of those injurious or beneficial to agriculture and forestry, with a view to developing practical methods for destroying the harmful ones and for promoting the increase and spread of the beneficial ones. The Bureau also investigates the habits, and develops methods of control, of insects affecting wild and domesticated animals. It investigates the honeybee and beekeeping practices and inspects adult honeybees imported under the act regulating their entry into the country. Some of its other work includes the development of new insecticides and fungicides, enforcement of quarantine and restrictive orders issued under the plant quarantine act and insect pest act to prevent the entry into the United States

of dangerous plant pests, and the regulation of the importation of nursery stock, fruits, vegetables, cotton, and other plants and plant products likely to carry pests. It enforces the act providing for the Mexican border inspection and control service to prevent the entry of the pink bollworm. It cooperates in the enforcement of the Terminal Inspection Act, and inspects and certifies as to freedom from injurious pests and diseases all plants and plant products intended for export.

Bureau of Human Nutrition and Home Economics.—This bureau performs research and offers educational services in connection with its findings on food, fiber, and other products of agriculture contributing to everyday living. Typical examples of the Bureau's research are: planning diets to safeguard health and obtain the fullest return from whatever food supplies are available, assaying foods for their vitamin contents, experimentation in vitamin requirements for humans, testing food values and cooking qualities of food, and so forth. Results of the research are made available through bulletins, press releases, radio talks, and exhibits.

Office of Experiment Stations.—The functions of this office date back to 1888. It administers federal funds for research in agriculture, for investigations directed toward increasing local and national food supplies and the production of oil, fiber, and other crops to meet industrial needs, and for the solution of critical problems in human and animal nutrition. It performs the coordinating functions of the Department of Agriculture and issues the *Experiment Station Record*.

Beltsville Research Center.—The Beltsville Research Center provides over-all operating services and related management necessary to effect efficient conduct of the work performed by various research agencies of the Department of Agriculture.

(c) *Bureau of Agricultural Economics*

This bureau is the channel for formulation of coordinated, over-all, Department-wide plans and programs relating to agricultural production, distribution, land utilization and conservation in their broadest aspects. It cooperates with State, county, and community planning groups, and through them encourages farmer participation in agricultural planning. It collaborates closely with the action agencies of the Department of Agriculture through a permanent coordinating committee and the exchange of liaison representatives. Plans and programs thus formulated, and approved by the Secretary of Agriculture, become the basis of operations for effectuating bureaus. In addition this bureau conducts basic economic research in farm management and practice, farm population and rural life, farm labor, tenancy, farm finance, insurance and taxation, marketing, transportation of farm products, rural opinions and attitudes, adjustments in production to probable demand for farm and food products, and land economics.

During the war, this bureau works in close cooperation with the war agencies. It supplies basic economic materials and analyses of domestic and foreign agricultural supply and demand conditions, agricultural shortages and surpluses, and prices. Special studies were made of the effects of the war upon American agriculture,

for use in formulating programs and policies aimed at successful prosecution of the war and in planning courses of action after the war.

3. Treasury Department

Bureau of Internal Revenue

Under a series of federal statutes beginning with the Act of 1886, taxes have been imposed by Congress on oleomargarine, adulterated butter, process or renovated butter, and on persons manufacturing or selling such commodities. Oleomargarine is defined as oleo, oleomargarine oil, butterine, lardine, suine, neutral lard extracts, tallow extracts, and mixtures of tallow, beef fat, suet, lard, lard oil, fish oil or fish fat, vegetable oil, annatto or other coloring matter, intestinal fat, and offal fat, if

- (a) made in imitation or semblance of butter,
- (b) calculated or intended to be sold as butter or for butter,
- (c) churned, emulsified, or mixed in cream, milk, water or other liquid, and containing moisture in excess of 1%, or common salt.

Where the oleomargarine is colored to resemble butter, a higher rate of taxes is imposed upon the commodity. Oleomargarine packages must be plainly labeled as such and words similar to butter, butterine, creamery, or dairy may not be placed on the package. The commodity tax is payable by the purchase of tax stamps which must be affixed to the package of oleomargarine.

For the purpose of taxation, butter that is adulterated is divided into three classes:

1. Butter in any way produced from different lots of melted or unmelted butter, or butterfat to which a substance has been added for the purpose of removing rancidity or deodorizing it, except butter made from sour cream, the acidity of which has been reduced with lime water before churning.
2. Butter or butterfat with which is mixed any substance foreign to butter as defined by law, for the purpose of reducing the cost of the product. This does not include mixtures taxable as oleomargarine.
3. Butter manufactured or manipulated by any process or with any material resulting in the absorption of abnormal quantities of water, milk, or cream. Emulsified or milk-blended butter comes within this class.

Ladled butter is taxable as adulterated butter if processed as described above. Adulterated butter must be so labeled and packages must contain the commodity tax stamps.

Process butter or renovated butter, for the purposes of taxation, is considered to be butter which has been subjected to any process by which it is melted, clarified, or refined and made to resemble genuine butter. Adulterated butter, however, is an exception. Process butter must be branded as such and must likewise carry tax stamps.

Manufacturers and wholesalers are required to have permits, to keep records, and to file inventories and returns. Retailers are limited in the amount of these products which they can sell. Manufacturers are also required to post bonds.

4. Department of the Interior

Fish and Wildlife Service

The Fish and Wildlife Service of the Department of the Interior deals with game and other birds; game, fur, and other land mammals; reptiles and amphibians; commercial and sport fishes and fisheries, including the shrimp, lobster, and shellfish industries; and fur seals, whales, and other marine mammals. The Service is both a law enforcement and a research agency. It is responsible for the administration of several federal statutes for the protection and conservation of migratory game and other birds, fur-bearing and game animals and fishes. The fishery conservation policies and recommendations of the Service are based upon extensive and diversified investigations of fish resources. The various projects are conducted by about twenty field stations in the major geographical regions of the United States. More than thirty important food fish, shellfish and crustaceans have been investigated.

In Alaska, the Service regulates and protects the salmon and other important commercial fisheries, as well as game fish.

The Service conducts studies for improving fishery methods, including the capture, preservation, utilization, and merchandising of fishery products and the compilation of statistics. It performs wildlife research on the damage caused by birds, rodents, fur animals, and predators on agricultural grazing in forested areas. A most important function of this Service is the determination of selective methods for the control of such pests.

5. Interstate Commerce Commission

In its enforcement of the Interstate Commerce Act, the Interstate Commerce Commission has jurisdiction over common carriers which transport food and any other material across State borders. Although the supervision actually exists over the carrier, regulations of the carrier may have a bearing on the material conveyed and result in some supervision of the product transported. Certain conditions surrounding the material being conveyed may affect the transportation service and thus may stimulate the enactment of regulatory orders. An example of this is the order issued by the Commission on May 29, 1943, in which a prohibition is set against the icing of refrigerator cars, or cars loaded with potatoes originating in the States of Georgia, South Carolina, North Carolina or Virginia. This order was issued by the Commission to prevent a shortage of railroad equipment and congestion of traffic because it appeared that shipments of potatoes in refrigerated cars from these four States were being iced unnecessarily, thereby unduly delaying the movement of trains.

6. Federal Trade Commission

The Federal Trade Commission, created in 1914 to prevent price-fixing agreements, boycotts, combinations in restraint of trade, and other unfair methods of competition,

was broadened in authority in 1938 by the Wheeler-Lea Act. This act conferred upon the Commission the jurisdiction over unfair and deceptive acts and practices relating to foods, drugs, cosmetics, and devices.

The Commission is authorized to make rules and regulations, issue cease-and-desist orders and, where appropriate, to apply to the courts for injunctions and for condemnation of merchandise misbranded under the terms of the act. Willful violations may be reported to the Attorney General and are punishable as misdemeanors. Imports not meeting requirements may be excluded by this agency.

During 1941, the Commission examined about 377,800 newspaper and other periodical advertisements and more than 871,900 commercial radio broadcast continuities of which more than 25,000 advertisements and over 24,500 continuities were marked for fuller study as containing representations that might be false and misleading. The Commission accepted from advertisers and others 234 stipulations to cease certain representations in radio and periodical advertising matter.

The Federal Trade Commission maintains a medical advisory service consisting of a medical director and two medical assistants, who review the validity of claims embracing the advertisement of foods and other substances made in cases instituted under the Federal Trade Commission Act.

7. Military Food Control Agencies

(a) War Department, Office of the Surgeon General

Veterinary Division.—The inspection of meat, meat food, and dairy products for the protection of the health of troops as well as for compliance with contract specifications is performed by the Army Veterinary Officer. The Veterinary Division of the War Department also inspects food for other organizations such as the Veterans' Administration, the National Guard, and the United States Soldiers' Home.

(b) Department of the Navy

Bureau of Medicine and Surgery.—Some of the functions performed by this office are analogous to those performed by the Veterinary Division of the Office of the Surgeon General of the War Department.

8. Emergency War Agencies

Office for Emergency Management

War Production Board.—The War Production Board was established within the Office for Emergency Management on January 16, 1942, with the functions of:

- (a) Exercising general direction over the war procurement and production program,
- (b) Determining the policies, plans, procedures, and methods of the several federal departments, establishments, and agencies in respect to war procurement and production, including purchasing, contracting, specifications, and construction, and including conversion, requisitioning, plant expansion, and the finance thereof. The Board issues directives in connection with such matters. A Food Requirements Committee, with the Secretary of Agriculture as its chairman, was appointed along with other working committees.

III. SUPERVISION BY GOVERNMENT AGENCIES

Office of Price Administration.—On April 11, 1941, the President ordered the establishment of the Office of Price Administration and Civilian Supply. This office was directed "to take all lawful steps necessary or appropriate in order to prevent price spiralling, rising cost of living, profiteering and inflation..." and to supervise the supply of goods for civilian needs. At the end of August, 1941, for administrative reasons, the Division of Civilian Supply was transferred to the Office of Production Management, but the intimate relationship between price control and the management of civilian supply was continued through the device of having the Price Administrator serve as the Director of the Division of Civilian Supply as well as serving as a member of the Supply, Priorities, and Allocations Board (created in August, 1941) and its successor, the War Production Board. In addition to the problems of prices, inflation, and hoarding of materials, the Price Administrator has two other principal functions:

1. To stimulate production of the necessary supply of materials and commodities required for civilian use in such manner as not to conflict with military defense needs.
2. To carry on a consumers' standards program such as had been previously carried on by the Consumers' Division of the Defense Commission.

Even though price functions have always constituted the core of the activities of this office, regulatory activity of an entirely different type was practically forced upon the Office of Price Administration in order to enable it to cope with its price problems. Not all the changes in products occurring subsequent to the issuance of maximum price regulations were the result of raw material restrictions or compulsory standardization enforced by the War Production Board. In the Emergency Price Control Act of January 30, 1942, the tendency to quality deterioration in inflationary periods was clearly foreseen and provisions were included to outlaw fraudulent practices. Section 2 (a) of the Act authorizes the Administrator to regulate or prohibit "manipulative practices" including "practices relating to changes in form or quality." In its food supervision work, the Office of Price Administration has issued regulations relating to meat and meat products. Grades for beef, veal, lamb, and pork were established, and it was made mandatory that all cuts of meat be marked with the grade designation. Definitions of the commercial cuts of cattle were established. Standards of fat and water content and of identity were established for Ground Beef, Ground Beef Patties, Ground Veal, Ground Veal Patties, Ground Lamb, Ground Lamb Patties, Ground Mutton, and Ground Mutton Patties. A prohibition was set against grinding meats in retail butcher shops for stock purposes. Ground meats and cubed steaks are required to be prepared on customer order only and in plain view of the customer.

The Emergency Price Control Act may be enforced formally along the following lines. Violators of price regulations face criminal prosecution with maximum penalties of a \$5000 fine and a year's imprisonment, or both, civil injunction suits, and revocation of selling licenses. In its early days, the major enforcement activities of the Office of Price Administration were in connection with rationing and price ceiling violations. In the latter instance, because of the novelty and scope of the regulations, educational methods were the measures employed rather than legal enforcement procedures.

Office of War Mobilization.—On May 27, 1942, the President ordered the establishment of the Office of War Mobilization in the Office for Emergency Management of the Executive Office of the President and the establishment within the Office of War Mobilization of a War Mobilization Committee. The functions of the Office of War Mobilization and the War Mobilization Committee are:

1. To develop unified programs and to establish policies for maximum use of the nation's natural and industrial resources for military and civilian needs, for the effective use of the national man power not in the armed forces, for the maintenance and stabilization of the civilian economy, and for the adjustment of such economy to war needs and conditions.
2. To unify the activities of federal agencies and departments engaged in or concerned with production, procurement, distribution, or transportation of military or civilian supplies, materials, and products, and to resolve and determine controversies between such agencies or departments except those resolved by the Director of Economic Stabilization.
3. To issue such directives on policy or operations to the federal agencies and departments as

may be necessary to carry out the programs developed, the policies established, and the decisions reached under this order.

Under the Executive Order of the President, all federal agencies and departments are required to execute directives of the Office of War Mobilization and make such progress reports as may be requested.

Combined Food Board, United States and United Kingdom.—This board was organized to formulate plans on questions concerning both the United States and the United Kingdom relating to the production, distribution, or transportation of food, agricultural materials from which food is derived, and equipment connected with the production of food and food materials.

Office of Fishery Coordination.—On July 21, 1942, the Secretary of the Interior was designated as Fishery Coordinator by the President. This designation was made for the purpose of developing and assuring a sustained production of aquatic food supplies essential to the conduct of the war, and for the purpose of coordinating the policies, plans, and programs relating to war that affect the fishery industries and the aquatic food supplies of the country.

II. STATE AGENCIES

It is apparent that the federal agencies, because of legal restrictions of jurisdiction, cannot and do not control the entire food supply of the nation. It is impossible to estimate the amount of food that crosses interstate lines without federal inspection, but it is plain that there are large quantities of food which are prepared and consumed on an intrastate basis which therefore do not come under the jurisdiction of federal agencies except in the special cases previously mentioned.

How is this food controlled? There is no standard, uniform, basic plan of operation or purpose in the States and their municipalities. Many States lack legal requirements, others lack personnel. Wide differences occur because of the variations in types and size of industries within a State as well as sizes of the States and their cities. A description of the food control in any one State cannot serve as a model of the food control in other States.

In the report of their survey of the distribution of sanitation services in the structure of State governments, Mountin and Flook³ describe the situation as follows:

"In contradistinction to the relatively well-defined programs for sanitation of water and sewerage, those which operate for control of foods and drugs are characterized by extreme diversity. Unlikeness obtains both in organization and in program content. Most striking, perhaps, is the lack of agreement as to what food and drug control should actually consist of. Administrative confusion is the natural result of this disagreement."

"The over-all pattern for the several States bespeaks multiformity along three fronts: First, in the particular types of services encompassed by food and drug control; second, in the official agency or agencies charged with responsibility for carrying out the program; and third, in the control methods that are employed."

The adoption by many States of legislation which is similar to and modeled after the Federal Food, Drug, and Cosmetic Act of 1938 is a trend toward desirable uniformity; but much more than this has to be accomplished before food control can be considered to be uniform even in basic principle throughout the States and their municipalities.

³ J. W. Mountin and E. Flook, *U. S. Pub. Health Repts.*, 57, 885 (1942).

New York State

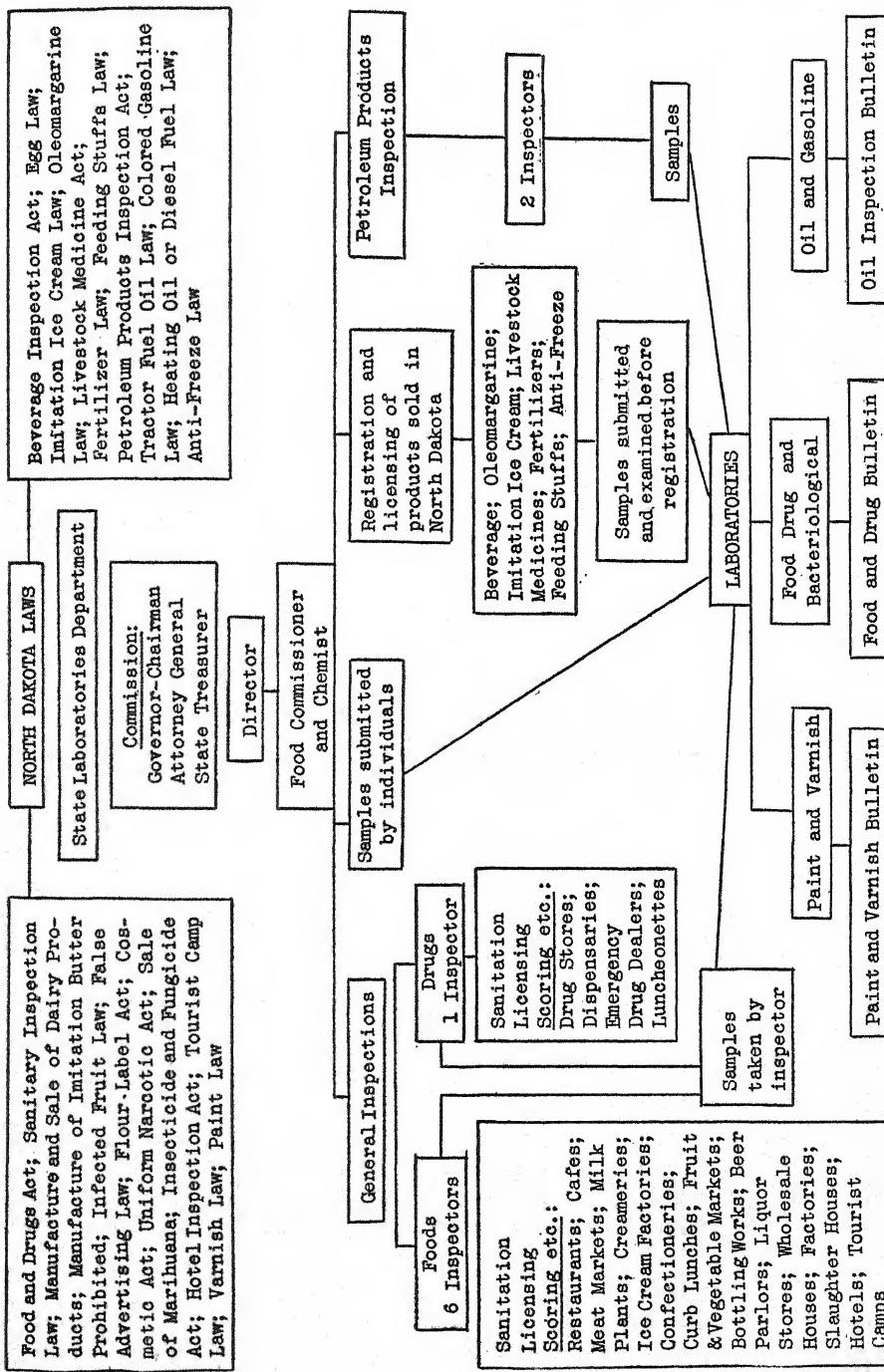
A description of the food control activities of official agencies of the State of New York is a good illustration of the enforcement policies of a State. The chart⁴ on page 123 depicting these activities in the State of North Dakota might well be compared with the food control work performed by State agencies in New York, as accomplished by the following departments: Department of Agriculture and Markets; Department of Health; Conservation Department; and Labor Department.

(a) *Department of Agriculture and Markets*

This department's jurisdiction extends over the entire State of New York, notwithstanding many "home rule" provisions granted the larger cities such as New York City. It has many powers and, in addition to carrying into effect the laws of the State and the rules of the department concerning agriculture, horticulture, farm and dairy products, and the cost, production, transportation, storage, marketing, and distribution of food, also has the power to enforce and carry into effect the laws relating to weights and measures and the investigation of deceptions in the quality, quantity, or character of foods produced, stored, sold, or offered for sale in the State, including the adulteration and misbranding of foods. It also has the power to seize, destroy, or denature filthy, diseased, or otherwise unwholesome foods, and to investigate, inspect, and supervise the sale of meat and meat preparations. These are in addition to the other powers of the department which do not refer directly to food supervision, such as obtaining and publishing statistics, helping establish cooperatives, and securing ample milk supplies for its municipalities. The law which this department operates under is known as the New York State Agriculture and Markets Law. It includes among other subjects more or less indirectly related to food the following food supervisory matters:

- Definitions for milk, cream cheese, butter, and oleomargarine.
- Receptacles for milk; their care.
- Adulterated milk, cream, skimmed milk, whey.
- Certified milk.
- Fat as basis for purchase of milk.
- Licensing of persons in charge of milk stations, plants, bacterial testing.
- Manufacture and sale of imitation butter, oleomargarine, butterine, imitation cheese.
- Use of false brands on cheese.
- Frozen desserts, definitions, licensing, pasteurization, vehicles, use of equipment.
- Post mortem* examination of animals, grading of herds, indemnities, tuberculosis, Bang's disease, baby veal.
- Grading of farm products, maple products, apples, eggs, grapes.
- Weights and measures, false labels, capacity of containers for milk.
- Kosher law enforcement.
- Method of sales of beer, bread, frozen desserts.
- Adulteration, misbranding, advertising of foods, honey, vinegar, canned goods, oysters.
- Cold storage licenses.

⁴ State of North Dakota, Lab. Dept., *Food and Drug Bull.* 69, July, 1943.



Food Control Activities in the State of North Dakota.

Licensing of canneries.

Milk control supervision and regulation of the entire milk industry of New York State, especially in regard to licensing, records, bargaining agencies, orders, price fixing and market-milk agreements, milk publicity.

In the performance of its functions, during 1941, the Bureau of Food Control of the New York State Department of Agriculture and Markets inspected 24,315 food establishments, such as abattoirs, bakeries, beverage plants, frozen dessert plants, restaurants, stores, and miscellaneous establishments. Some 20,000 inspections were made of eggs and more than 22,000 dozen were candled for grading purposes. Condemnations were made of 986,977 pounds of food, and 10,049 samples of food were taken, including beverages, canned foods, chocolate drinks, hamburgers, ice cream, jams, jellies, preserves, maple sirup, condiments, and meats. About 2700 licenses were issued to frozen dessert dealers, 150 to canneries, and 794 to abattoirs. Of about 8130 inspections made on frozen dessert equipment, 284 violations were found. Twelve inspectors assigned to kosher law enforcement made 7493 inspections and 1038 investigations. As a result of this work, 61 convictions were obtained. Violations of the kosher law are covered in the New York State Penal Code.

Thus, as its name implies, the Agriculture and Markets Law enforcement is mainly one of safeguarding economic markets, although the Bureau of Food Control does perform some sanitary inspection of foods for wholesomeness and fitness for human consumption. Another aspect of the marketing control afforded by this department can be found in the work of its Division of Milk Control. During 1941, this division was concerned primarily with the protection of milk producers by the bonding of milk dealers, the checking of weights and tests in the purchase and sale of milk, with problems of administering milk-marketing orders and the general milk control regulations. The milk-marketing orders are price-fixing orders previously referred to in the section concerning the Agricultural Marketing Administration, which become effective within the State of New York when accepted by at least 75% of the producers of milk for a marketing area. New York City, which is one of the three areas for which milk orders are issued, is regulated both by the New York State Department of Agriculture and Markets and by the United States Secretary of Agriculture, and the percentage of out of State producer approvals required is 66 $\frac{2}{3}$ %. Each of the three price-fixing orders provides for payments to a fund from which the expenses of administration are defrayed. In each of the marketing areas, offices have been established, and staffs of auditors check the reports and records of each dealer subject to the order.

For the license year ending March 31, 1941, there were 5135 milk dealer licenses issued ranging in fees from \$3 to \$5000. The licensing of milk dealers involves field investigations covering adequacy of supply in given territories, character and financial standing of applicants for licenses, promptness of payments to producers, and prices paid and charged.

In addition to enforcing the price-fixing orders, inspectors check milk as received from producers at milk plants for watering or skimming. Matters relating to the

licensing and bonding of operators, licensing of milk plant managers, milk samplers and testers, and checks upon amounts due and promptness of payments to producers for milk are also covered by milk control investigators.

In addition to the activities of the Bureau of Food Control and the Division of Milk Control, work indirectly affecting the food supply is performed by the following bureaus of this department: Bureau of Milk Publicity; Bureau of Agricultural Industrial Exposition; Bureau of Animal Industry; Bureau of Plant Industry; Bureau of Weights and Measures; Bureau of Traffic and Transportation; Bureau of State Institution Farms; Bureau of Statistics.

(b) *Department of Health*

The law of the State of New York under which the New York State Department of Health operates is the Public Health Law, and includes provision for a State Sanitary Code to be enacted by the State Public Health Council.

The State Sanitary Code applies to, and is effective in, all portions of the State except the City of New York. In the matter of food supervision, the State Commissioner of Health is charged with certain specific duties. It is his duty to protect and promote the health and welfare of the people of this State by inspecting, regulating, and supervising the sanitary quality of milk and cream distributed, consumed, or sold within this State, whether produced within or without the State. It is his duty to cause investigations, studies, and surveys to be made within and without the State to determine among other factors, the following:

(a) The current sources of supply of milk and cream for household consumption and for manufacturing purposes and the amount produced by such sources.

(b) The adequacy of existing State and municipal machinery for the enforcement of sanitary regulations and the extent to which impurities have escaped prevention and detection.

(c) The proper State or local agencies or combinations of agencies to be entrusted with the duties and responsibilities of effective sanitary control and inspection of milk and cream in its various local and State-wide phases.

(d) The food control regulations in the State Sanitary Code which concern Milk, Cream, Camps, Hotels, Lodging Houses, Boarding Houses, and Restaurants.

Milk and cream are defined and permits are required for their handling and sale. The production of milk is regulated with particular emphasis being placed on mastitis, illness among milk handlers, the sanitary condition of stables and yards, the cleanliness of milking animals and hands of milkers, and testing for tuberculosis, Bang's disease, and mastitis.

There are general regulations covering the construction and maintenance of milk utensils and apparatus, the cleansing, sterilizing, and storing of utensils, the water supply and flush closets, and the temperature of the milk and cream.

The State Public Health Law includes a section, also applicable to New York City, whereby no milk or cream can be brought into the State unless the producer and

shipping plant of such milk or cream has a permit from the State Department of Health and has received an inspection within a 12 month's period.

The *State Sanitary Code* contains provisions regarding milk shipping stations and bottling and pasteurizing plants. Pasteurization is defined, and bottling and capping machines are required to be used. The building must be of sanitary construction.

Camps are regulated and food is controlled at camps by specific sections in the *State Sanitary Code*. Restaurants are also regulated with special reference to cleanliness, health of employees, refrigeration of foodstuffs, use of poisonous materials, and water supply.

During 1940 the New York State Department of Health made 2584 inspections of pasteurizing plants. There were 19,715 dairy farm inspections made of out-of-State farms and 391 dairy farm inspections of in-State farms. Some 236 other plants were investigated, in addition to the pasteurizing plants. Because, during 1940, the field of restaurant inspection and sanitation was relatively new to the State Department of Health, its preliminary efforts in this work were directed almost entirely along educational lines.

(c) *Conservation Department*

The New York State Conservation Department has specific powers along certain limited lines of food supervision, namely, shellfish control. These powers arise out of the functions of the department in connection with conservation, as its name implies. Under the conservation law, a Bureau of Marine Fisheries is provided for; its duties are to examine all shellfish lands within the State to ascertain their sanitary condition and then to certify which are shellfish areas and from which areas shellfish may be taken for use as food. These lands are called certified areas. In addition, the law covers the drinking or floating of shellfish, water supply used in washing, and the sanitary conditions of boats and houses. A digger's permit is required as well as a shipper's permit. Shellfish must be properly tagged and labeled.

In order to determine the sanitary quality of shellfish and of the lands from which they are dug, sanitary surveys are made. Bacteriological examinations of shellfish, shucked stock, and the waters are also performed periodically. The New York State Conservation Department works in close cooperation with the United States Public Health Service and the New York City Department of Health in controlling the production, handling, and sale of shellfish.

To show the operation of the triple control, we may take as an example the case of a shipper of shellfish in Long Island who buys his oysters from local diggers and ships the shellfish to the Fulton Fish Market in New York City and to Boston for resale to restaurants, hotels, fish stores, or directly to consumers. The Long Island shipper would make an application to the New York State Conservation Department for a certificate of approval as a shipper. This Department investigates shipper's facilities, methods, and the premises from which the shellfish will be shipped.

It also investigates and makes certain that the premises comply with its sanitary requirements, that the personal habits of all workers are satisfactory, that the shellfish are taken from certified waters by diggers who have permits, and that the shellfish are properly tagged. When all conditions are met, the shipper's application is approved and his name is certified as an approved shipper. Since the shellfish are intended to be sent out of the State, a certificate of compliance with the regulations of the United States Public Health Service is issued to the shipper by the Service. Indorsement of State shellfish control measures and certifications for shippers in interstate commerce by the United States Public Health Service is based upon the existence of State regulations which are equivalent in their requirements to those set forth in the "United States Public Health Service Minimum Requirements for Endorsement of State Shellfish Control Measures and Certifications for Shippers in Interstate Commerce." Since New York State standards are not lower than those in the minimum requirements, the Long Island shellfish shipper's name is certified by the United States Public Health Service. This listing by the United States Public Health Service is the best guarantee available to interstate receivers, in this case the Boston dealer, that the oysters grown in another State (New York) are of a satisfactory sanitary quality and are shipped by a certified shipper whose premises comply with all sanitary requirements and whose handling of the shellfish is proper and satisfactory.

When a New York City dealer engages in the shellfish business, he must secure a permit from the New York City Department of Health. The New York City dealer's establishment is inspected and similar sanitary standards as provided for by the State and the United States Public Health Service are required. After all conditions are met, the New York City Department of Health issues a permit. This permittee may then receive and sell shellfish from a dealer certified by the New York State Conservation Department (or the agency of some other State from which the shellfish are to be shipped) and the United States Public Health Service.

Other food activities of the New York State Conservation Department include the control of fish and game from the point of view of their conservation.

(d) Department of Labor

The work of the Department of Labor in connection with food control is mentioned for the sake of completeness, rather than to indicate that food supervision is an important part of its work. The Labor Law of the State includes a few sections relating to bakeries and similar factories. These sections require that new bakeries be built or installed on the first floor level or above, and makes exceptions for those bakeries installed before the passage of the law. During 1941, the Department of Labor inspected 1433 bakeries throughout the State of New York, including New York City.

III. MUNICIPAL AGENCIES

Food is supervised by many local agencies in towns, counties, and cities in the United States, as well as by the State governments and federal agencies. Different

departments have jurisdiction of similar food supervisory functions in different cities. In New York City, for example, food is supervised in the main by the Department of Health, with some additional supervision afforded by the Department of Markets.

New York City

(a) Department of Health

Actual, direct food control is maintained by the Department of Health as far as possible over all foods, milk, and shellfish held, kept, or offered for sale in the City of New York. Every effort is made to control the sanitary condition of every establishment in the city where these foods may be found. This includes food factories, warehouses, storehouses, jobbers' establishments, terminals, docks, piers, markets, railroad yards, waters from which shellfish are taken, milk plants, and slaughterhouses, and restaurants, bakeries, butcher shops, and the other types of retail food establishments. In addition to these establishments within the city, the New York City Department of Health has a staff of country inspectors who investigate the source of supply of the 5,200,000 quarts of milk which are shipped to New York City each day from about 55,000 farms in New York State, Pennsylvania, New Jersey, Vermont, and Massachusetts.

Bureau of Food and Drugs.—The legal basis for the work of the Bureau of Food and Drugs of the Department of Health of the City of New York is provided by the *Sanitary Code* of the City. This code contains sections specifically relating to many foods such as milk, milk products, frozen desserts, cream, shellfish, sausages, confectionery, almond paste, cured meats, flour, butter, cheese, and eggs. There are sections and regulations in the *Sanitary Code* relating specifically to certain industries and establishments, including milk farms, country receiving stations, trucks, poultry slaughterhouses, shellfish shucking establishments, frozen dessert plants, cattle slaughterhouses, wholesale food establishments, restaurants, butcher stores, fish stores, cold storage warehouses, and butter whipping and printing establishments. There are also general sections and regulations referring to any food and to all food establishments.

Enforcement of the *Sanitary Code* and supervision of the food supply is accomplished in many ways. First, efforts are made to educate dealers and the public. Meetings are held with representatives of industry at which enforcement problems are discussed, and actual instruction is given in food handling. Lectures and talks are presented to audiences in public schools, colleges, and similar public places.

The second method of law enforcement is the permit system. See page 130. Before a permit is issued to a food dealer, or before his premises are approved as a source of supply, all requirements of the *Sanitary Code* must be met. Permits are renewed annually in most cases; and before a permit is reissued an inspection is made to determine compliance. Where an operator permits violations to exist after a permit has been issued, action may be taken to revoke the permit. The same procedure may be applied in the case of approvals of sources of supply for milk or shellfish.

In addition to removal of violations during the course of issuance or denial of a permit, or approval or exclusion of a source of supply, violators may be given individual written notices, or groups of violators in an industry may be instructed and warned at an official meeting. Food violations are determined by examination of the product by the inspector in the field, or, in many cases, by a chemical or bacteriological analysis of a sample of the food taken by the field inspector. Where a violation exists involving unwholesome or decomposed food, the food may be embargoed for separation purposes, or condemned forthwith by the inspector.

The staff of the Bureau of Food and Drugs numbers about 235, divided into a field service of about 140 and a staff in the central headquarters of about 95. The personnel includes inspectors, chemists, physicians, veterinarians, microscopists, administrative officers, and other specialists. The field service is made up of two groups, a city force and a country force. The only inspectors who work outside the city are those attached to the Country Milk Division.

The Bureau of Food and Drugs is made up of the following food divisions:

Division of Milk Inspection.—This division has a country branch and a city branch. New York City receives its 5,200,000 quarts of milk daily from about 55,000 dairies with one million head of cattle located in five States around New York City. This milk goes into 356 country milk receiving stations, 106 of which are equipped for pasteurization.

The country force supervises milk production and handling outside the City of New York. The country inspector examines milk at the receiving stations for temperature, odor, sediment, and physical appearance. Unsatisfactory milk is rejected and a microscopic examination made to determine the cause. Cleanliness of equipment and processing operations at receiving stations and pasteurizing plants is supervised. In 1943, a total of 1,643,680 cans of milk were examined by country milk inspectors and 17,427 cans were rejected.

The city milk inspector supervises the milk as it is brought into 47 pasteurizing plants and 282 wholesale milk depots engaged in processing and distributing milk and milk products. He samples milk and milk products for chemical and bacteriological examinations. Thus, during 1943, 11,630 samples were submitted for chemical analysis and 20,430 samples for bacteriological examination. The city milk inspector makes field tests to determine whether the milk or cream is properly pasteurized, and supervises the pasteurization process and sanitary conditions of milk establishments. This branch of the Bureau of Food and Drugs also supervises the manufacture of ice cream at wholesale plants in the City of New York and in an area ten miles outside the city in the case of those manufacturing plants which ship ice cream into the city. During 1943, this division made 60,248 inspections in the country and city, condemned some 414,526 pounds of milk and milk products, and prosecuted 662 dealers for *Sanitary Code* violations.

Shellfish Division.—This division supervises the production and sale of shellfish and fish in New York City. It polices those waters of the city from which shellfish are not permitted to be taken. It performs bacteriological examinations of the

shellfish in the New York City market. It enforces sanitary requirements for fish and shellfish establishments. During 1943, this division made 21,125 inspections, condemned 12,984 pounds of fish and shellfish, investigated 12 cases of typhoid fever and prosecuted 21 dealers. Bacteriological examinations of 1264 samples of shellfish were made.

Wholesale Division.—This division was established in January, 1941, and supervises the sanitary conditions and food production in all wholesale food establishments in the city except milk, shellfish, and frozen dessert operations. During 1943, the Wholesale Division made 22,532 inspections and condemned 1,245,734 pounds of foodstuffs.

Retail Division.—This division supervises the food which is handled in approximately 100,000 retail establishments in the city. In addition to its food control work, as such, it also makes certain that the methods of food handling are satisfactory and that the premises are clean, sanitary, and otherwise in a condition which will not endanger the wholesomeness of the food present. During 1943, this division made 115,752 inspections of restaurants, bakeries, groceries, butcher shops, and other retail establishments. Food in the amount of 452,249 pounds was condemned, and 2311 dealers were prosecuted.

Chemical Laboratory.—During 1943, the chemical laboratory analyzed 19,238 samples brought in by inspectors of all divisions. In addition to analytical work, the chemists perform research on food control problems in which the need for chemical analysis is indicated. An example is the development of the New York City rapid field test to determine whether milk is properly pasteurized. This is based on the destruction of the phosphatase enzyme if milk is properly pasteurized.

Food Poisoning Supervision.—Prevention of food poisonings and tracking down the causes of food poisoning, although highly specialized, is not the work of any one division but of all of them. A supervisor of food poisoning correlates the information and organizes the investigation of food poisonings. This supervisor also acts as liaison officer between the Bureau of Food and Drugs and the Bureau of Preventable Diseases which handles the medical aspects of food poisoning investigations. During 1943, food poisoning cases involving 1636 persons were investigated.

Permit Division.—The issuance of permits granted by the Bureau of Food and Drugs is performed by the Permit Division, which is in a separate bureau of the Department of Health. Every permit acted upon by the Bureau of Food and Drugs is issued only after the premises are found to comply with the requirements of the *Sanitary Code*. Where an applicant fails to meet these specifications, his application for a permit is denied. Permits are issued for the following types of food establishments and related equipment, processes, and sales practices:

1. Milk and milk products

Class A—For a dealer who operates a pasteurizing plant in New York City.

Class B—For a dealer who operates a milk and/or milk products depot.

Class C—For a dealer who operates not more than one vehicle, in the delivery or distribution of milk and/or milk products, and who does not maintain his own pasteurizing plant or milk depot but

utilizes the facilities of a milk depot located in the City of New York and under permit from the Board of Health.

Vehicles for delivering milk and milk products.

Vitamin D Processing Permit—For treatment of milk to increase its vitamin D content.

Vitamin D Transportation Permit—For bringing into the City of New York milk which has had its vitamin D content increased by a known process.

Source of supply must be approved.

2. Restaurants.
3. Poultry slaughterhouses.
4. Frozen dessert manufacturers.
5. Sale or manufacture of foods at wholesale.
6. Bakeries—wholesale, retail.
7. Digging (bayman), shipping or selling shellfish.
8. Cattle slaughterhouse.
9. Sale of horsemeat.

(b) Department of Markets

The work of the New York City Department of Markets in food control parallels that of the similar agency in the State of New York. The markets, peddlers, stands, and pushcarts in the city are supervised by the Department of Markets. This agency makes economic surveys of the food supply of the city and, through its Bureau of Weights and Measures, performs control activities to prevent frauds. It enforces the State Agriculture and Markets Law for the detection of misbranded and adulterated foods and prosecutes dealers who violate this law. It also provides a market news radio reporting service for consumers, and collects marketing statistics and prices to aid the food merchants in the city.

The work of Mountin and Flook,⁵ in surveying the distribution of health services in the structure of a State government, especially in regard to the sanitation of foods and drugs and of food handling establishments, shows clearly the complexity of food control by State agencies, and may well be applied to most government agencies controlling food. These authors report:

"The acme of complexity in sanitation activities occurs in that portion of the program which involves food and drug control (including milk and shellfish sanitation) and restaurant supervision. Confusion is due to disagreement regarding what should be covered, who should be responsible, and how the desired results should be attained. As a result, the division of authority and variation in procedures are so heterogeneous that they almost defy classification and description in accordance with any pattern that could be devised."

Although in recent years, particularly since 1938, there have been a number of reorganizations and consolidations of food control agencies and functions, these have taken place almost wholly on the federal level. Within the State, county and city governments, the need has been urgent for a long time for a clarification of functions and jurisdictions, and for a simplification of control. These are prerequisites for uniform and effective food supervision in our country.

⁵ J. W. Mountin and E. Flook, *U. S. Pub. Health Repts.*, 57, 885 (1942).

Chapter IV

FOOD GRADING: SANITARY AND QUALITY CONTROL

T. A. SAMUELSON

Bismarck, North Dakota

Food has always been a very important factor in the daily life of man, and its distribution from producer to consumer is, under our present mode of civilization, a problem which will ever tax the knowledge and ingenuity of our most able food specialists. The object of the distribution of food is, of course, to supply the ultimate consumer with the moisture, proteins, fats, carbohydrates, minerals, and vitamins which are required for his vegetative existence. It is of equal importance that foods arrive in a clean, wholesome condition, free from adulterants or deleterious substances of any kind. No one, however, has been or will be entirely satisfied even when he has met these basic requirements. It is not enough that a food be nutritious and fit for human consumption; it must also possess a number of qualities which have come to be required for the appearance and palatability of the product or of the tempting dishes prepared from it. A discussion of the sanitary aspects of food grading necessarily centers around the activities of such law enforcement agencies as the Federal Food and Drug Administration, the Livestock and Meats Division, Food Distribution Administration and other agencies (federal, State, and municipal) whose activities are in part to enforce laws which must be complied with by food handlers to safeguard public health. This is in contrast to a discussion of quality control which, to a large extent, does not involve mandatory requirements for food dealers but only voluntary practices which may be followed.

I. SANITARY CONTROL

1. Introduction

Let us first consider the methods by which it is assured that foods are fit to be eaten. No attempt will be made to go into all phases of the assurance of a wholesome food supply. The discussion will be confined to the significance in the program of the examination of finished food products. We will not discuss meat inspection by the Meat and Livestock Division, Food Distribution Administration of the United States Department of Agriculture¹ or other activities based largely upon inspection

¹ Regulations Governing the Meat Inspection of the United States Department of Agriculture, *B. A. I. Order 211 revised*. Issued Dec., 1922.

of raw materials and enforcement of sanitary conditions during manufacture and distribution. The subject cannot be considered entirely on the basis of the standards which are enforced by government food officials since such standards necessarily represent the minimum requirements of sanitary control. Since they are designed for enforcement purposes, they are based upon the accomplishments which are attained in good commercial practice plus a reasonable tolerance. They are not to be considered as standards which are to be aimed at by producers and manufacturers. However, the maximum amounts of bacteria, molds, extraneous matter, etc., allowed by food officials before definite legal proceedings are instituted indicate inadequate regard for sanitary control; and a study of a number of such factors will present a fairly comprehensive picture of the whole general problem. It must be borne in mind that examination of foods as they appear on the market is often a very small part of the sanitary control which is required by law or normally practiced. The standards are often only indications of the effectiveness of other measures taken.

Before going further it would be well to review the portion of the Federal Food, Drug, and Cosmetic Act which relates to adulteration of food:

"A food shall be deemed to be adulterated (a) (1) If it bears or contains any poisonous or deleterious substance which may render it injurious to health; but in case the substance is not an added substance such food shall not be considered adulterated under this clause if the quantity of such substance in such food does not ordinarily render it injurious to health; or (2) if it bears or contains any added poisonous or added deleterious substance which is unsafe within the meaning of section 406;² or (3) if it consists in whole or in part of any filthy, putrid, or decomposed substance, or if it is otherwise unfit for food; or (4) if it has been prepared, packed, or held under insanitary conditions whereby it may have become contaminated with filth, or whereby it may have been rendered injurious to health; or (5) if it is, in whole or in part, the product of a diseased animal or of an animal which has died otherwise than by slaughter; or (6) if its container is composed, in whole or in part, of any poisonous or deleterious substance which may render the contents injurious to health."

The food laws of most of the States follow this wording very closely, and the enforcement of sanitary requirements is based largely upon such broad provisions. Specific requirements for particular foods are often set up by regulations issued by or standards

² Section 406 reads as follows: "(a) Any poisonous or deleterious substance added to any food, except where such substance is required in the production thereof or cannot be avoided by good manufacturing practice shall be deemed to be unsafe for purposes of the application of clause (2) of section 402 (a); but when such substance is so required or cannot be so avoided, the Secretary shall promulgate regulations limiting the quantity therein or thereon to such an extent as he finds necessary for the protection of public health, and any quantity exceeding the limits so fixed shall also be deemed to be unsafe for purposes of the application of clause (2) of section 402 (a). While such a regulation is in effect limiting the quantity of any such substance in the case of any food, such food shall not, by reason of bearing or containing any added amount of such substance, be considered to be adulterated within the meaning of clause (1) of section 402 (a). In determining the quantity of such added substance to be tolerated in or on different articles of food the Secretary shall take into account the extent to which the use of such substance is required or cannot be avoided in the production of each such article, and the other ways in which the consumer may be affected by the same or other poisonous or deleterious substances. (b) The Secretary shall promulgate regulations providing for the listing of coal-tar colors which are harmless and suitable for use in food and for the certification of batches of such colors, with or without harmless diluents."

adopted by the various officials charged with enforcement of the laws. These requirements are not always uniform, nor is it desirable that they should be so in all cases. Varying conditions in different parts of the country make it reasonable to expect that the same degree of care in marketing a commodity may result in quite different standards. For example, mold counts in dairy products are normally lower in cold weather than in warmer weather.³ In general it may be said that federal requirements are the minimum and that State and municipal requirements may be more stringent. Too great emphasis on uniformity would, in many instances, tend to retard rather than encourage progress in food control.

2. Bacteria

Foods are harmful to health when pathogenic bacteria, other harmful organisms, or toxic substances of bacterial or other origin are present. It is not within the scope of this chapter to discuss the various methods which are used by manufacturers and distributors to eliminate or to prevent the growth of harmful bacteria in their products. For that matter, it is not possible to do more than scratch the surface in discussing the means of examining the finished products to determine how well sanitary control was exercised in the various processes involved in production and distribution. Suffice it to say, that, from a sanitary standpoint, bacteriological examination of food and food products is one of the most valuable examinations which can be made. Such an examination may consist merely of determining the number of bacteria present or it may consist of actual isolation and identification of particular organisms. The nature of the examinations can perhaps be best shown by considering a number of typical examples.

(a) Water

Of the examples which might be cited, analysis of water will be considered first since it is of great importance in public health, since there has been a great deal of work done in the field, and since it demonstrates practical methods for routine analysis. The most logical and direct method for determining the safety of a water from a bacteriological point of view would be testing it for the presence or absence of harmful bacteria; and the standard for drinking water would simply be that it contain no living pathogenic organisms or excessive amounts of any microbiological life. However, because of the huge preponderance of nonpathogenic bacteria, it is doubtful that the presence of such pathogens could be established in all cases even by employing the most elaborate bacteriological procedures; and, for routine purposes, such isolation and identification is out of the question. Bacteriologists have therefore developed an indirect method of determining the presence of a broad class of bacteria, the presence of which shows the probability of dangerous contamination. This group of bacteria (the coliform group) is relatively easy to identify and its presence is an almost certain indication of pollution of the water with excreta

³ Report on the analyses of butter. State Laboratories Dept., Bismarck, North Dakota, *Food and Drug Bull.* 67.

from man or other animals, which in turn shows the possibility of the presence of pathogenic bacteria of intestinal origin—the type which is generally responsible for diseases transmitted through the water supply. The adoption of standards for water is, then, not so simple as it may at first appear. The standards must be such, as to give reasonable assurance of the absence of fecal pollution, but at the same time be practical in that they do not require a great deal of unnecessary laboratory procedure. The standards which are generally followed by those who wish to assist in providing a sanitary water supply by analysis of the water as it is delivered to consumers are those adopted by the Public Health Service of the Federal Security Agency for waters which are to be used in trains, omnibuses and other common carriers in interstate commerce.

(b) *Milk*

Bacteriological examination of milk is of considerable importance in all programs for controlling the quality of milk sold to the public. As in the case of water analyses, attempts are rarely made to determine the presence of bacteria that are harmful to health. Nonpathogenic bacteria are normally present in milk in considerable numbers; nevertheless the total number of bacteria present is a fair indication of the

TABLE 15
BACTERIOLOGICAL REQUIREMENTS FOR VARIOUS GRADES OF MILK

Grade	Log average plate count per cc. not to exceed—	Log average direct microscopic count of clumps per cc. not to exceed—	Log average direct microscopic count of individual organisms per cc. not to exceed—	Arithmetic average reduction time in hours to be not less than—	
				Milk, etc.	Cream ^b
A (consumed raw)	50,000	50,000	200,000	8	7
B (consumed raw)	1,000,000	1,000,000	4,000,000	3½	2½
C (consumed raw)	^a	^a	^a	^a	^a
A (to be pasteurized)	200,000	200,000	800,000	6	5
B (to be pasteurized)	1,000,000	1,000,000	4,000,000	3½	2½
C (to be pasteurized)	^a	^a	^a	^a	^a
A (pasteurized)	30,000	...	...	...	...
B (pasteurized)	50,000	...	...	...	...
C (pasteurized)	^a	...	...	...	...

^a No limit.

^b These arithmetic average reduction time limits represent twice the log average plate count limits corresponding to the figures in the preceding column.

sanitary quality of the milk. The Public Health Service *Milk Ordinance and Code* which is approved by the Public Health Service, Federal Security Agency, and the Bureau of Dairy Industry, United States Department of Agriculture, and has been recommended for adoption by States and communities is the most universally accepted authority for milk control work. The ordinance sets up grades (A, B, and C) according to the sanitary conditions under which the milk is produced and distributed and according to the bacterial count of the milk as received by the consumer. Bac-

teriological requirements for the various grades of milk as given in the ordinance⁴ are tabulated in Table 15, and are mentioned in Volume I, page 413.

While on the subject of bacteriological standards for milk, we must also mention "certified" milk. The term as applied to milk has a very definite meaning, since it can be applied only to milk which has been produced under rigorous specifications and conforms to rigid standards adopted by the American Association of Medical Milk Commissions, Inc. The bacteriological standards adopted by the Association⁵ are as follows: "Certified milk shall contain not more than 10,000 bacteria per cubic centimeter as determined by the examination of original bottles at the time it is delivered to the consumer. Certified milk to be pasteurized shall contain not more than 10,000 bacteria per cubic centimeter before pasteurization in samples taken at the pasteurizing plant and not more than 500 bacteria per cubic centimeter after pasteurization and as determined by examination of original bottles at the time of delivery to the consumer Certified milk shall contain fewer than ten organisms of the *Bacterium coli* group (*Escherichia* or *Aerobacter*) per cubic centimeter of milk."

(c) Other Products

There are many other products besides water and milk in which bacteriological analysis is significant in determining sanitary quality. In most cases, however, the analyses are not employed on a wide scale, or the amount of work which has been done has not resulted in widespread adoption of standards. Lack of recognized standards does not mean that interpretation of analyses is any less significant, provided such interpretation is made by a competent authority who is informed of all the facts in each case. For some products, bacteriological standards have been adopted by one or more public agencies, but for the most part are rather limited in their effectiveness because of lack of sufficient recognition. There is a great deal of work being done which may eventually lead to establishment of bacteriological standards which will be as widely recognized as are those for milk. An example of such progress is the sanitary control of frozen desserts, the U. S. Public Health Service having issued a *Frozen Desserts Ordinance and Code* which they recommend for adoption by States and communities. Work done by the American Public Health Association and the Association of Official Agricultural Chemists in standardizing methods of procedure will be a great aid toward such an end. Important among the products examined bacteriologically at the present time are dairy products of all kinds, bottled beverages, shellfish, canned goods, dehydrated foods, and frozen foods. Definite standards for maximum bacterial plate counts as applied to government purchases may be found in federal specifications for a number of products. An index to federal specifications may be obtained from the Superintendent of Documents, Washington, D. C., for fifteen cents.

⁴ *Public Health Bull.* 220 (1939).

⁵ *Methods and Standards for the Production of Certified Milk*, adopted June 9, 1942, by the American Association of Medical Milk Commissions, Inc., 1265 Broadway, New York.

3. Mold

Mold is objectionable in most food products not only because it makes the food unpalatable but also because it indicates that proper sanitary control was not exercised in handling the finished product and/or the ingredients used therein. Mold growth may appear on bread, meat, fruits, vegetables, comminuted foods, beverages, and, in fact, on almost all moist foods; but because it is usually found on the surface, moldy material is readily condemned and rejected. In many cases, notably processed foods, molds may not be detected macroscopically and yet the product may contain mold, usually introduced through the use of moldy ingredients.

(a) Butter

A typical example of this condition is butter made from moldy cream. It has been shown by Vandaveer and Wildman⁶ that there is a distinct relationship between the amount of mold found in cream and the sanitary conditions under which the cream was produced, and that the amount of mold mycelia found in butter indicates the sanitary quality of the cream used in its manufacture. Cream which is judged unfit for buttermaking may be seized and destroyed under the Federal Food, Drug, and Cosmetic Act; and most cream buyers refuse to purchase such cream. Sometimes, however, illegal cream is purchased and used in the manufacture of butter, either through deliberate disregard of the sanitary significance involved or through carelessness in examining the cream. The quantity of mold mycelia in the butter is an index which is often used to determine whether or not objectionable cream was used. The method described by Wildman⁷ shows the relative amounts of mold mycelia present in butter, including both living and dead organisms, so that the results obtained actually reflect the condition of the cream before pasteurization. No universally accepted standard has been adopted as to the amount of mold which can be considered in excess of that which may normally be present in butter due to unavoidable contamination of cream produced and delivered with all due regard for the principles of sanitation. The Federal Food and Drug Administration completed a survey on the subject in the summer of 1939, and came to the conclusion that butter made from good sour cream produced and handled with reasonable care should show a mold mycelia count of well under 60% and could, in fact, be kept in the neighborhood of 20% without serious difficulty.

Methods which determine the amount of living mold in butter are also used as an index to the quality of the product. Samples are plated out on suitable media, incubated, and the colonies of molds (and yeasts) counted. Results obtained usually do not indicate the quality of the cream used in buttermaking, but indicate rather the effectiveness of pasteurization and subsequent sanitary control in the plant. Considerable use is made of this method by the butter industry in their control work.

⁶ R. L. Vandaveer and J. D. Wildman, *J. Assoc. Official Agr. Chem.*, 23, 693 (1940).

⁷ J. D. Wildman, *J. Assoc. Official Agr. Chem.*, 22, 76 (1939).

The *Laboratory Manual* of the American Butter Institute contains recommendations of tentative standards which are based upon actual creamery control work.

(b) *Tomato Products*

Another example of the significance of the presence of mold filaments for the sanitary quality of food are the various products made from tomatoes. There are a number of molds which attack tomatoes, causing their decay. Although these molds can usually be detected easily on the surface of the tomatoes, often much of the growth is below the surface or in the cracks of defective fruits and is not readily observed. It might be expected, then, that it would be rather difficult to reject all moldy tomatoes and manufacture a mold-free product from the remainder of the crop. It is recognized that such a difficulty does exist and the standards which are enforced are lenient enough to allow for the difficulties encountered in good manufacturing practice. A study of the changes in the amounts of mold which have

Year	Product	Maximum Mold Allowed
1931	Tomato products	50% of fields positive
1938	Tomato juice	25% of fields positive
1940	Other tomato products	50% of fields positive
	Tomato juice	15% of fields positive
	Catsup, puree, paste	40% of fields positive

been considered by the Food and Drug Administration to show adulteration in tomato products⁸ will indicate the improvements which can be made in sanitary control by the food industry. Sanitary control measures which may be considered adequate today may be obsolete in the future, so that the standards which are enforced by government food officials may be expected to show considerable variation from time to time. Mold is usually determined in tomato products by the Howard method.⁹ The accompanying table is a brief history of the interpretation which has been made of the results obtained. The figures are the maximum per cent of fields showing mold which were allowed before proceedings were instituted on the basis of adulteration.

4. Insects and/or Rodents

Insects and/or rodents will attack practically all foods if they can gain access to them; and any food which has become so infested is subject to seizure under the Food, Drug, and Cosmetic Act. The presence of living worms or insects can usually be detected by examining the material macroscopically, noting the presence of the invaders and/or the evidences of their life processes or destructive consumption of food. Worm-eaten fruits, vegetables, meat, candy, and the like are examples of

⁸ U. S. Dept. Agr., *Notice to Manufacturers of Tomato Products*, June 17, 1940.

⁹ *Methods of Analysis*. 5th ed., Assoc. Official Agr. Chem., Washington, D. C., 1940, p. 522.

infestation which are most often noted by consumers and retailers, so that the infested foods are immediately taken off the market. Worms in fish are sometimes difficult to detect since, in the case of certain fish (*e. g.*, whitefish), the worms may be present within the flesh and can be detected only by cutting slices through the meat and noting the presence of worms and pus. The detection of insect parts and rodent hairs is of most significance in the sanitary control of comminuted or processed foods such as butter, cheese, tomato catsup, apple butter, corn meal, dates, and peanut butter in which the presence of extraneous matter is not readily observed.

5. Dirt

Sediment testing of milk and cream is widely used by buttermakers and law enforcement officials to determine the cleanliness of their products. The method most often used¹⁰ is essentially that of straining one pint of milk (or two ounces of cream diluted with eight ounces of water) through a filter disk one inch in diameter, washing the residue, and determining the amount of sediment on the disk. The determination makes possible the grading of the samples on the basis of the total amount of dirt present, the grading usually being in terms such as "clean," "fairly clean," "slightly dirty," and "dirty." The sediment on the disks can be examined further for the presence of insect parts and rodent hairs, which are reported separately and are of particular sanitary significance. Somewhat modified methods are used for examining butter and cheese, but the principle involved is that of making a suspension of a definite weight of material and filtering it in such a way as to eliminate most of the components normally present. The examination of the residue and the significance given to it are very nearly the same as for sediment in milk and cream.

For certain products, such as apple butter and tomato catsup, containing cellular material, a filtration method cannot be used to separate normal solid particles from foreign particles. Flotation methods are employed based on the fact that, upon the addition of gasoline to an aqueous suspension of the material, hairs or insect parts are wetted by the gasoline and remain in the gasoline layer with most of the other material remaining in the aqueous layer. The gasoline layer is decanted and filtered and the residue examined. The methods do not show the amount of dirt which may be present but do show the degree of insect or rodent infestation. Any number of rodent hairs or insect parts in excess of the few which may be present as a result of accidental or unavoidable contamination constitutes adulteration. Just what tolerance must be permitted depends to some extent on the nature of the product involved and the difficulties in eliminating all insects, worms, or rodent filth from the raw materials used. Any infestation which appears to be due to unsanitary conditions in the manufacturing plant cannot be tolerated. Laboratory examination of finished products is often used to corroborate unfavorable reports by sanitary inspectors.

¹⁰ *Standard Methods for the Examination of Dairy Products*, American Public Health Association and the Association of Official Agricultural Chemists.

6. Added Injurious or Deleterious Substances

(a) General

Foods must not contain any added substances which will render them injurious to health. The detection of the presence of such ingredients is an important phase of the examination of foods from a sanitary standpoint. Foreign substances which may be harmful to health may enter foods in various ways: They may be added as preservatives, colors, bleaching agents, etc.; they may be introduced by accidental contamination or from the use of improper manufacturing equipment or containers; or they may be carried over from the raw materials used. In all cases in which the presence of the foreign substances in the finished product can be avoided in good manufacturing practice, it should be done. No tolerance is given to the deliberate addition of any harmful substance which is unnecessary. A good example of such addition is the use of sulfites in meat products. The sulfites are objectionable in meats not only because they may be harmful in themselves but also because they destroy bad odors and impart a red color to meat so that old stale meat can be made to appear fresh. The practice is prohibited by most of the States and by the Livestock and Meats Division, Food Distribution Administration (Bureau of Animal Industry) which has jurisdiction over meat sold in interstate or foreign commerce.

The Federal Food, Drug, and Cosmetic Act does not specify what preservatives may or may not be used in foods. It does, however, prohibit the use of any added poisonous or deleterious substance which is unsafe; and it is therefore up to the manufacturer to make certain that any ingredient which he may use in food has been proved to be safe. Special regulations may be issued prohibiting the use of certain specific substances in foods; and the adoption of standards for foods may preclude the presence of ingredients not mentioned in the definition. One or more of the States specifically prohibit the use of certain preservatives, although in some cases they make exceptions for small amounts which may be present in certain products because they are deemed to be unavoidable, desirable, or necessary. These amounts are, of course, so limited that there is little or no danger to health involved. Examples of some compounds which are prohibited or restricted to some degree by the Federal Government or by one or more of the States are formaldehyde, copper salts, boron compounds, formic acid, β -naphthol, salicylates, pyroligneous acid, benzoate of soda, which is usually limited to one-tenth of one per cent, and sulfites, which are prohibited in most foods, though the use of sulfur dioxide is permitted as a bleach and various standards have been adopted as to the quantity permitted in dried bleached fruits.

(b) Spray Residue

The problem of spray residue on fruit is an example of the necessity for the establishment of limits for the presence of an added poisonous substance required in production. Use of sprays such as lead arsenate, calcium arsenate, and fluorides by fruit growers is necessary to control insect pests; but it is also essential that the fruit,

when put on the market, does not contain large enough quantities of the poisonous ingredients to be harmful to health. When the Federal Government set out to solve the problem, it had to establish tolerances which could be met by the industry without prohibitive difficulty and yet would not present a health hazard. This was particularly difficult because arsenic and lead are cumulative poisons and it is hard to prove just what quantities taken over an extended period of time would be harmful. Tolerances have varied from time to time. The most recent tolerances promulgated by the Federal Food and Drug Administration, based on a report of the subject by the Public Health Service, became effective in August, 1940, and provided that apples and pears in interstate commerce contain not more than 0.05 grain of lead per pound and 0.025 grain of arsenic (as arsenic trioxide) per pound. The tolerance for fluorine remained at 0.02 grain per pound as had been set in November of 1938.

II. QUALITY CONTROL

1. Introduction

Up to this point only those factors of food grading have been considered which have a very definite bearing on the health of the consumer. We might say that, for the most part, the factors considered place a food into one of two categories: foods which are safe for human consumption, and those which may be harmful to health and may therefore not be sold. The remainder of this chapter will consider a further classification of the foods in the former group.

In discussing the quality of food, it is sometimes a bit difficult to distinguish between standards of quality and standards of identity. Take, for example, the case of vanilla extract which, to bear the name, must contain at least 50% of standard extract of vanilla bean. Synthetic compounds such as vanillin and coumarin can be used as flavoring agents and an imitation product can be made which closely resembles true vanilla extract. Vanilla bean extract, however, is considered by many to have flavoring qualities which cannot be attained in imitations; and since the extract contributes to flavoring quality as well as flavoring strength, the requirement for the amount which must be present could be considered as a quality standard. In the following discussions, however, we will not consider quality in such a manner. All subsequent references to quality will concern only foods which are wholesome and safe for use and which comply with established standards of identity and strength.

The Federal Food, Drug, and Cosmetic Act does not contain provisions which, to any great extent, concern the quality of the food sold. The act provides for the establishment of minimum quality standards for canned goods; and any product which does not meet such standards must be conspicuously labeled with the legend:

BELOW STANDARD IN QUALITY
GOOD FOOD—NOT HIGH GRADE

The act also prohibits the use of any substance which makes the product appear better than it really is; and, of course, any product which is labeled with a quality grade such as "Grade A" or "Choice" must meet the standards established for such a grade. It is evident, then, that the regulatory control of quality by food officials acting under food and drug laws is not very great. While minimum standards will prevent the sale of below-standard food not properly designated as such, such standards might in fact result in actually lowering the quality of the pack by some manufacturers. The aim of the manufacturer might be only to meet the minimum requirements so that he could market as low priced a product as possible. This has been the case in the establishment of minimum standards of strength for certain foods which resulted in actually lowering the strength of the average product on the market. However, quality standards cannot be considered exactly the same as standards of identity and strength, since quality is more apparent to the consumer and he will demand the quality which he desires and is willing to pay for. Aside from price, consumers buy foods according to the taste, odor, and appearance of the product; and, on a competitive market, it is to the advantage of the manufacturer that his products be as attractive and palatable as he can make them.

2. Quality Factors

Quality control by the food industry is a very important factor in merchandising. Accurate scientific control of production is rapidly replacing old-fashioned methods based largely upon the judgment of the persons in charge of the various operations. Experienced operators may become very skilled in judging the progress of manufacturing processes; but whenever the personal element is involved there is a definite possibility that each batch will vary in some of its qualities even when production is controlled by the same individual in the same plant. Whenever scientific control can be substituted for personal judgment, or used in conjunction with it, a step has been made toward greater assurance of uniformity in the finished product, a factor which is of great importance in food merchandizing because it is so strongly demanded by the consumer. Quality control goes a great deal further today than a mere examination of the raw materials and the performance of a few tests during the manufacturing process. Examination of the finished products before they are placed on the market, too, goes further than determining the chemical composition and making certain that all packages meet legal standards of identity, strength, and wholesomeness. A manufacturer may obtain the finest of raw materials, possess the best of manufacturing equipment, and employ the most modern methods to produce a product which meets all legal standards but which still fails to measure up consistently to consumer demands. Hence, it is necessary to employ measures which assure uniformity of quality factors of foods, a number of which will be considered briefly: size, color, texture and body, defects, flavor and aroma, utility, and keeping qualities.

(a) Size

Separating foods into various groups according to size, in the case of many commodi-

ties, is perhaps the first major problem of grading. As a rule, such grading is done principally from an economic standpoint, since certain sizes are in greater demand than others and consequently bring higher prices on the market. This is true of eggs, oysters, most fresh fruits and vegetables, nuts, and other products which are sold in whole form. For products which are sold by number (*e. g.*, eggs) the significance of size grading is chiefly that variation in size means a corresponding variation in total food value, so that smaller sizes should be cheaper than larger sizes. Closely related to such obvious differences are variations in usable food from various sizes of commodities sold by weight, in which case waste as a result of peeling, coring, and other operations must be considered. In general, the larger sizes are the most economical; but medium sizes are more often preferred since they are usually superior in other desirable factors. In many cases there is no waste in using a commodity, and preference for a certain size is based entirely upon qualities of flavor, texture, etc., which are associated with the size, or upon esthetic reasons. Grading for size is done to a large extent by hand. The machines devised and used for the purpose are generally of the type which accomplish separation by sorting according to volume (as screening) (see page 14) or weight. Uniformity of piece size in such products as sliced, diced, shredded, and quartered canned fruits and vegetables is desired mostly for the sake of appearance, especially when the products are to be used in fancy salads and desserts.

(b) *Color*

Color is a very important factor in determining the quality of foods because it may be an index to other factors, such as maturity in fruits and vegetables, freshness in meats, or richness (egg content) in certain baked goods. Consumers have very definite color preferences even in those cases in which the color does not reflect other desirable qualities in foods, and are often willing to pay a premium for products which have exceptional color appeal. Hence, producers and manufacturers do all that they can to develop and retain the best possible color in the foods which they market. Uniformity of color is almost as important as degree or brightness of color. It is of particular significance in products in which the color is controlled, at least to some degree, in the manufacturing processes. An accurate control of color must be based upon use of standards of some sort for making comparisons, because individuals cannot "remember" colors well enough to detect slight changes which may occur from time to time. Color charts are generally used as references though more scientific control in accurately measuring color is achieved by using colorimeters, photometers, and spectrophotometers.

A great deal of research is constantly being carried on to determine causes for, and to develop methods of preventing, loss of color. As an example, to conform with improvements in the industry, the definition of canned peas adopted under the Federal Food, Drug and Cosmetic Act was recently amended to allow the use of traces of alkalies (sodium carbonate, calcium hydroxide, and magnesium hydroxide) for the purpose of retaining the natural green color of the peas. In some cases

artificial color is used as an aid in obtaining a uniform product. Artificial colors are not allowed in products for the purpose of making an inferior product seem better than it really is; but their use is often necessary to assure a product acceptable to the consumer. For instance, butter made from cream obtained from different localities or at different seasons of the year may vary in color; the addition of an artificial yellow color is the usual means of compensating for the seasonal and sectional variations. Discoloration after packing is sometimes an important problem in merchandising foods. The presence of small amounts of sulfur or of traces of copper and iron sometimes causes a black color to appear in canned goods. The presence of chlorine (sometimes introduced as an impurity in water) causes bleaching in certain food products, as does exposure to air and light. There are a great many apparently insignificant details to watch in color control, and there is much yet to be accomplished in attaining the desired degree of control. There is no method available for preserving foods in such a manner as to retain all the original color of fresh fruits and vegetables.

(c) *Texture and Body*

Texture and body in food products refer to the structural make-up, variations of which have a great deal to do with acceptability of a number of foods. For example, there is a general preference for "mealy" potatoes, "crisp" celery, "creamy" candy, "fluffy" or "fine-grained" cakes, "thick" cream, and "flaky" pie crust. Texture and body control such factors as toughness, slicing quality, pouring quality, and spreading quality. Since these qualities often depend in large measure upon conditions existing during manufacture, an accurate control of operations is essential. Accurate control of such factors as the nature and proportion of ingredients, the time and temperature of processing, the amount of stirring, and the rapidity of cooling may sometimes determine whether or not the product will have the proper consistency. The use of stabilizers is important in obtaining the proper texture and body of a number of processed foods (*e. g.*, the use of emulsifying agents in the preparation of salad dressing). Homogenization is a good example of a process designed to assure uniform and permanent body.

Not only are scientific methods being applied to actual manipulations in manufacturing processes but also to the examination of finished products in determining how well they meet the desired standards. For example, canners may determine the degree of tenderness of the peas which they pack by use of a mechanical device based upon measuring the weight required to press a cotyledon to a definite fraction of its size.¹¹ If results show that standards of tenderness, which the canner has decided upon as worthy of maintaining, are not attained, he will then attempt to trace the cause. The investigation may go all the way back to the maturity of the raw materials or may show some defect in processing which, in the particular case of tough peas, may be such a seemingly minor factor as hardness of the water in which they were cooked. The apparatus mentioned for testing peas can, in modified form

¹¹ U. S. Dept. Agr., *Circ.* 164 (1931).

if necessary, be used for testing the tenderness of a number of other products. Toughness in cheese has been determined by dropping a weighted spear from a definite height and noting the depth to which it sinks in the cheese. Actual viscosity determinations are sometimes made to determine the body of cream which, incidentally, is not due entirely to the fat content but is also influenced by conditions of handling and storage. Gas holes in bread may actually be measured and slices compared with slices (or photographs) of a standard loaf of bread. Oil globules in an emulsion may be examined microscopically to determine their size. All such methods, which are based upon accurate scientific measurements, take the guesswork out of quality control and are important factors in progress.

(d) *Defects*

Webster defines "defect" as "want or absence of something necessary for completeness or perfection." If we were to consider the term in such a broad manner, all qualities of foods would come under the one topic, and no product would ever be entirely free of defects. In grading foods, "defects" generally refers to the presence of harmless extraneous materials or of mechanical bruises, to physiological or pathological imperfections in the foods themselves, or to imperfections in workmanship. Since no food will ever reach perfection, standards must be established for tolerances to be allowed for each specific defect which is likely to be present in objectionable proportions. Hence, standards are established and maintained for: the amount of skin allowed in canned tomatoes; peel, core, and seeds in applesauce; broken, spotted, or otherwise discolored peas; limb rubs, scabs, stems, insect injuries, and leaf tissue in canned fruits; crooked spears of asparagus; sand in peanut butter; hollow hearts in potatoes; and almost innumerable similar defects. Numerical ratings can be assigned to the relative degree of absence of defects in many foods, and control can therefore be based upon rather specific standards.

Most defects are eliminated from foods by operators who sort out extraneous matter and imperfect specimens from the supply of raw materials or from the finished products. Much of the sorting is done by hand; but machinery and scientific apparatus are often used to supplement hand labor. For example, x-ray technique is used to detect the presence of stones and dirt in peanuts, nuts and bolts in canned goods, citrus fruits which have "crystallized" because of frost damage, potatoes with hollow centers, and other analogous imperfections. Defects can never be entirely eliminated from foods but, with better methods of production processing, and testing, they are being much more accurately controlled. Very little food now appears on the market represented as high quality which is not practically free of defects.

(e) *Flavor and Aroma (Tastes and Odors)*

Palatability is of course the ultimate quality which determines whether or not food will be acceptable to the consumer. There are four basic taste sensations (sour, salt, sweet, and bitter); but taste is so intricately tied in with odor and combinations of tastes and odors that the variations in the degree of perfection which may be

attained are almost unlimited. While there is no way of making certain that a food will be acceptable to the palate by exercising direct control over flavor and aroma during manufacturing processes, there are many precautions which are taken to assure greater probability of retaining natural flavors and developing others which are desirable. For instance, after a careful selection of materials, accurate control is necessary to obtain the desired qualities of flavor and aroma in roasting coffee beans, pickling cucumbers, malting barley, curing cacao beans, and fermenting grapes in the production of wine. Accurate control can be maintained over such factors as acidity and carbonation of bottled beverages, exclusion of foreign odors and flavors, and retention of volatile oils. The proportion of ingredients in processed foods is of great importance in all quality factors, but is especially so in flavor control. Most products owe their characteristic flavor to the particular combination of taste sensations which are blended together. Control of the proportion of ingredients results in control of the ultimate flavor combination. Sanitation, too, plays a very important part in flavor control since growths of bacteria, molds, and yeasts are often the cause of the development of unpleasant flavors and odors in many food products. Certain microorganisms, on the other hand, are vital in obtaining desired qualities in some foods: Controlled souring of cream is accomplished by adding bacterial starters to pasteurized cream to obtain a desirable flavor for buttermaking, certain molds are grown in some cheeses, and yeast not only makes the bread dough rise, but also contributes to flavor. Chemical changes may also affect flavor. A good example is the oxidation of fats, with the accompanying rancid odor and taste; the oxidation is accelerated by the presence of minute traces of copper and iron, so control may include elimination of contact with such metals.

Not only is it necessary to control flavors which develop in a product, but it is also necessary to avoid the absorption of foreign odors by the finished product. Some foods take up odors very readily; and it is essential that they be properly stored if they are to retain their own normal flavor qualities. This is very important in the case of baked goods, which must be stored in well-aired rooms to prevent the mixing of various odors with a resultant "bakery taste" so often objected to by consumers.

In some industries expert tasters are employed who taste the raw materials, or the products made from them, and determine those having desirable qualities. Such tasters become very skilled in detecting slight variations in odors and tastes, and can often accurately associate such variations with the variety of raw materials used, methods of processing, or even minor modifications or errors in the processes. The detection of off-flavors is usually most significant in grading foods for flavor and, as will be exemplified later in discussing quality grades for butter, the problem can be given a semblance of scientific accuracy by assigning definite values to specific flavors which might be encountered. However, much will always depend on the experience and judgment of the individual taster. It is doubtful whether there will ever be any methods developed which will eliminate the personal element in grading foods from this standpoint. Surely the connoisseur will always be the final authority in the judgment of the finer qualities of flavor and aroma.

(f) Utility

When the manufacturer has a product which satisfies him as to size, color, texture, defects, odor, and taste, he can be reasonably sure that it will be acceptable to the public. However, he often conducts elaborate investigations to determine just how his product will survive the test of actual use. For example, tests are made regularly by flour millers to evaluate the baking quality of flour (Vol. I, pp. 654, 694); other ingredients such as dried milk, dried eggs, and yeast are also often subjected to actual baking tests before being placed on the market; in some plants, research workers are constantly attempting to learn by practical methods exactly what problems the housewife may encounter in using the product. By such means the manufacturer may learn of defects in his product which would otherwise come to his attention only through customers' complaints. Research workers note the effects which slight variations in composition or other qualities will have on the utility of the products, endeavor to find new uses for them, and develop new products. Research by manufacturers is of particular importance because it is through such efforts that knowledge is gained about foods and that progress is made in quality control.

(g) Keeping Qualities

Closely related to the methods used by the manufacturer to test his products by putting them to actual use are methods used to test keeping qualities. When a manufacturer takes extensive precautions to produce a high-quality product, he wants to be sure that it retains the quality right up to the time that it is received by the ultimate consumer. He therefore frequently subjects his packaged products to the extreme conditions of temperature and humidity possibly encountered in distribution. By such practical tests, he can determine the extent to which he may rely upon his methods of preservation. It is the final check on the effectiveness of pasteurization, sterilization, dehydration, vacuum packing, use of chemical preservatives, use of electrical methods for insect control, and other processes which he may employ to extend the keeping period of his products. It is also the means of determining what type of package is best suited to each particular product and of testing new packaging ideas.

3. Quality Standards

Since there are such a number of factors in quality control which are very important in distribution, it is evident that there is a need for universally accepted quality standards. A manufacturer who wishes to pack a high-quality product would purchase high-quality raw materials. Each producer would probably have a different idea as to the meaning of the term "high quality," so that the manufacturer would have considerable difficulty in obtaining uniform commodities. Manufacturers would also have different ideas regarding quality, and would establish standards to suit their own purposes. Hence, wholesalers and retailers could not be certain of the quality of merchandise received from various sources. The use of a definite

system of grading by all parties involved in the buying and selling of foods provides a common basis for intelligent bargaining. Anyone wishing to buy foods needs simply to specify the grade desired to the seller, who will know the requirements of the product which he must furnish. The consumer also frequently wishes to buy according to the quality of the product; however, he too often has no idea of the quality of his purchase until the container has been opened and the contents have been inspected. In order that the retailer and the consumer may arrive at a common understanding regarding quality and price, it is necessary that the consumer have a convenient way of knowing the grade of the product. This is most readily accomplished by labeling each item with the grade. The grades must, of course, be universally accepted so that, whenever used, they signify the same quality material; and they should be as simple as possible to avoid confusion in their use.

(a) *U. S. Grades and the Food Distribution Administration*

Variations in the degree of excellence of various foods have been recognized in the nomenclature of manufacturing and marketing interests for over a century. Terms to designate quality were perhaps first limited to use at local markets where the need for them in establishing price differentials had been demonstrated. From such a meager beginning, some of the terms gained in popularity until they were in use by a substantial portion of an industry. It is no wonder, then, that different systems of grading were established for various commodities, and that the interpretation and application of each grade were not uniform. With the development of better methods of preserving and transporting foods, markets were greatly extended and the need for universally accepted quality standards then more clearly demonstrated.

The Federal Government, recognizing the need for such standards, has established "United States Grades" for a large number of commodities. Any person interested in buying or selling food may make use of U. S. Grades and of grading services offered by the Agricultural Marketing Administration of the United States Department of Agriculture. The Agricultural Marketing Administration (first known as the Agricultural Marketing Service) was established July 1, 1938. To it were transferred many of the duties formerly handled by the Bureau of Agricultural Economics, including the authority to establish standards for farm products. The Agricultural Marketing Administration was consolidated with the Food Distribution Administration in December, 1942. See page 110.

Most of the grades which have been developed were designed for wholesale trade; and one of the principal requirements for them is that they can be applied in all parts of the country and from year to year in spite of normal variations in the quality of the crop. In other words, "U. S. Grades" always refer to the same quality of product, provided they are uniformly interpreted and applied. Since quality grades are weighted standards based upon a series of objective tests, there is no sharp differentiation between adjacent grades and there are likely to be a number of borderline products which cannot easily be classed as, for instance, "Grade B" (minimum requirements) or "Grade C" (maximum requirements). To insure uniformity, official grading is

performed only by authorized representatives of the Food Distribution Administration who have been specially trained to apply the specifications for grades. The grading service is not mandatory but is available on request to anyone who desires it and is willing to pay the costs. An example of the service offered by the Administration will be discussed briefly below in connection with the grades for canned fruits and vegetables.

The number and nature of the grades set up by the Food Distribution Administration vary according to the essential characteristics of each particular food and to the influence of commercial practices. A good many foods are divided into a large number of subdivisions for trade purposes. Classification is based upon factors inherent in the supply which affect the market value of each particular group. Grades are usually the final commercial grouping and are generally applied to a rather uniform part of the food supply. Since grade nomenclature is not uniform because it was designed to follow the grades used in trade practice, it is necessary to learn the system of grades for each particular product in which one is interested. The following discussions of grades are intended only to present a general picture of the systems of classifying and grading foods. Details on grades and specifications for grades can readily be obtained from the Department of Agriculture, Food Distribution Administration, Washington, D. C.

Carcass Beef.—The first *Official United States Standards for Grades of Carcass Beef* were set up in 1926, but were rather complicated in that specifications were established for each class of beef: steer, heifer, cow, bull, and stag. Under such a system, it would not be apparent to one who was not well informed about the nature of the grades and the class designations that, for example, "U. S. Choice Steer" would be a better quality cut of beef than "U. S. Choice Cow." The system was simplified in 1939 by providing a single standard for grading the classes of beef (heifer, steer, and cow) which are most likely to be sold over the block by retail meat dealers. The grades include the variations in quality attributed to class (e. g., cow beef is not eligible for the top grades, U. S. Prime and U. S. Choice). In 1942, grade terminology was as follows: U. S. Prime, U. S. Choice, U. S. Good, U. S. Commercial, U. S. Utility, U. S. Cutter, U. S. Canner.¹² See also Vol. I, pp. 441-445.

Cutter and canner grades are not often sold over the block; hence, from the consumers' point of view, the newer system of grading requires only a knowledge of the first five terms and is relatively easy to comprehend. Designation of the quality of bull meat and stag meat is based upon the same series of grades as for other classes of beef; but specifications are established for grades according to the characteristics of each class. U. S. Prime bull is the highest quality of bull beef obtainable, but is inferior to U. S. Prime heifer or steer or to U. S. Prime stag. The grades of carcass

¹² The Office of Price Administration, in establishing ceiling prices on foods, eliminated "Prime" from the grades of beef and veal carcasses. In October, 1942, the Secretary of Agriculture amended the *Official Standards* by suspending the grade specified as "Prime" for beef and veal for the period during which maximum price regulations are in effect. During this period, all beef, veal, and calf carcasses meeting the specifications of "Prime" are to be graded as "Choice."

beef (as well as of practically all meat) are based upon conformation, finish, and quality, which have been defined as follows:¹³

Conformation.—Conformation is the form, shape, outline, or contour of the carcass. It ranges from the smooth, plump, well-rounded, well-proportioned conformation of the most highly developed carcass yet produced to the rough, rugged, irregular, disproportional conformation of the thinnest, boniest, most poorly bred carcass produced.

Finish.—Finish is fat and includes the fat which appears on the outer surface of the carcass, on the inner walls of the chest and abdomen, around the kidneys and the seams of fat which sometimes lie between the larger muscles. Finish involves not only the quantity of fat but its quality and distribution. Finish ranges from that of the carcass which is almost completely covered both inside and outside with a smooth layer of firm fat, to that of the carcass which is totally lacking in discernible fat.

Quality.—Quality consists largely in characteristics of the flesh. It includes texture, tenderness, juiciness, flavor, and color. Quality also involves ratios or proportions of flesh to bone and of fat to lean meat, and the distribution of fat through the muscle tissues, commonly known as marbling. Quality, therefore, ranges from that of the small-boned, heavily fleshed, highly finished, well-proportioned carcass possessing a very high degree of tenderness, juiciness, and flavor and very fine fiber or texture, to that of the very large-boned, thinly fleshed, ill-proportioned carcass with an extremely low degree of tenderness, juiciness, and flavor, and extreme coarseness in texture.

The method used by the F. D. A. graders in marking meat which they have graded for quality consists of the use of a roller stamp on the carcasses in such a way that the stamp mark will appear on the retail cuts. In this manner, the ultimate consumer will know the quality of any meat which has been officially graded. When bull beef or stag beef is graded and identified, the terms "bull" and "stag" must be used as well as the name of the grade. The stamp used is different from, and should not be confused with, the round purple stamp "U. S. INSP'D. & P'S'D." which is placed on meat by inspectors of the Livestock and Meats Division, Food Distribution Administration (Bureau of Animal Industry) and which signifies that the meat was inspected and passed from a sanitary standpoint.

Veal and Calf Carcasses.—Veal and calf carcasses are divided into classes (steer, heifer, and bull) and are further classified according to weight (lightweight, medium-weight, and heavyweight). Variations in quality due to classes or to weight ranges are relatively insignificant, and separate specifications for grades are not necessary for each subdivision. Six grades have been established (see footnote 12 on page 149) ranging as follows: U. S. Prime (No. A1), U. S. Choice (No. 1), U. S. Good (No. 2), U. S. Commercial (No. 3), U. S. Utility (No. 4), and Cull (No. 5). The first five grades are the most familiar in retail trade and are stamped.

Lamb and Mutton Carcasses.—Lamb and mutton carcasses are divided into the same grades as veal and calf. The first five grades may sometimes be stamped in retail trade.

Pork Carcasses.—For commercial purposes pork is divided according to classes: barrows, gilts, sows, stags, and boars. Further classification is made according to the weight of the carcasses and the use to which they will be put. Grades (U. S.

¹³ Official United States Standards for Grades of Veal and Calf Carcasses, U. S. Dept. Agr., S. R. A. A. M. S. 114 (1928).

No. 1, U. S. No. 2, U. S. No. 3, and Cull) are established for each of the following groupings: roasting pork carcasses, shipper-pork carcasses, meat-type (bacon) pork carcasses, fat-type (butcher) pork carcasses, sow (packing) pork carcasses, and stag pork carcasses. There is no grading and stamping service for pork since a large portion of the meat that appears as fresh cuts in retail trade is U. S. No. 1 and there is no demand for such service.

Dressed Poultry.—Dressed poultry is classified according to kind, age, sex, and weight as, broilers, fryers, roasters, stags, capons, fowl, and old roosters. Further classification is made according to the method of plucking (scalded, semiscalded, or dry picked), dressing (drawn or undrawn), chilling (fresh dressed, fresh hard chilled, or frozen), finishing (milk fed or grain fed), and packing (dry or iced). See Volume I, page 528. Grade terminology established for dressed chickens and turkeys is as follows: U. S. Special (AA), U. S. Prime (A), U. S. Choice (B), and U. S. Commercial (C). Quality grades are based upon quality factors of amount of flesh, amount of fat, tenderness, conformation, dressing, and bleeding. Most grade labeling of poultry has been accomplished by placing the grade identification on the outside of packing boxes, but the present trend is toward marking individual birds for retail trade. This is being accomplished by the use of tags and of stamps on wrappers of individually wrapped birds.

Eggs.—Most States have egg laws which include the provision that all eggs be candled before they are placed on the market. Grades have been set up in a number of States, but most laws do not provide for the sale of eggs on a graded basis. Although the degree of success in the enforcement of State egg laws is variable, the results usually accomplished are the elimination of eggs unfit for food and the classification of eggs into groups according to size. Grade nomenclature is not uniform from State to State. For example, the top grades are variously described as Fancy, Specials, Fresh, A No. 1, Grade A, Extra, etc. Several States have adopted the grades set up by the United States Department of Agriculture for individual eggs. U. S. Standards are provided for four qualities of clean, sound-shell, edible eggs, namely: U. S. Special, U. S. Extra, U. S. Standard, and U. S. Trade; for three qualities of dirty, sound-shell eggs, namely: U. S. Extra Dirty, U. S. Standard Dirty, and U. S. Trade Dirty, and for one quality of eggs with checked or cracked shells, namely: U. S. Check. Specifications for grades are based upon qualities of the shell, size and movement of the air cell, mobility and visibility of the yolk, and viscosity and clarity of the white. Standards for size have been adopted by many of the States and agree fairly well with the standards proposed by the United States Department of Agriculture for retail grades, as may be seen in the accompanying table.

U. S. D. A. retail grades	Minimum average weight per dozen	Minimum weight requirement for individual dozens
Large.....	.24 ounces.....	.22 ounces
Medium.....	.20 $\frac{1}{2}$ ounces.....	.19 ounces
Small.....	.17 ounces.....	.15 ounces

The U. S. Standards and Grades have been developed to meet the needs of the various parties involved in buying and selling eggs. Separating eggs into various groups according to grade cannot be accomplished in actual practice in such an efficient manner that each individual egg in each group will meet the requirements of the grade. Different grades have therefore been established for use by buyers, wholesalers, and retailers. These grades differ in the permitted range of quality and tolerances. For instance, "Wholesale Grade U. S. No. 1 Extras" must contain 80% U. S. Extras or better, whereas "Wholesale Grade U. S. No. 4 Extras" must contain 50% U. S. Extras or better, with the balance in each case composed of U. S. Standards or better.

Grades for eggs may be carried through to the consumer by use of certificates of quality and by use of seals. The identification may be placed on each individual carton of eggs when the grading has been done by authorized representatives of the F. D. A. The seal shows the grade, the date of grading, and the size of eggs in the carton.

Creamery Butter.—Creamery butter is graded on a numerical basis from "U. S. 93 Score" to "U. S. 85 Score" inclusive, and "No-Grade." The score is based upon flavor and upon defects in body, color, and salt. Over 30 different flavors which can be identified are listed and evaluated in the standards, with weighted scores given in most cases according to the prominence of the flavor. Examples of the flavors, and the ratings given to them, are as follows: fine—93; pleasing—92; slightly cooked—93, definitely cooked—92; slightly onion or garlic—87, definitely onion or garlic—86, pronouncedly onion or garlic—85. The official U. S. Score of each individual sample of creamery butter is determined by deducting from the flavor rating of the sample the amount by which the total ratings in defects in body, color, and salt are in excess of the ratings for defects permitted in these factors for butter of the particular flavor rating. Defects in body, color, and salt are rated as follows:

Gummy, leaky, spongy or weak, crumbly, or sticky body, wavy color, color specks, and sharp salt: slight, $\frac{1}{2}$ point; definite, 1 point.

Ragged-boring, mealy or grainy, and streaked or mottled color: slight, 1 point; definite, 2 points.

High color (unnatural): pronounced, 1 point.

Gritty salt: slight, 1 point; definite, 2 points.

As an example of grading, suppose that the only off-flavor which can be detected in a sample is one identified as "slightly cooked": The flavor rating would be 93. "U. S. 93 Score butter shall possess a fine flavor. It may possess a very slightly normal feed or slightly cooked flavor. It is made from cream to which a culture (starter) may or may not have been added. The total permitted defects in body, color, and salt are limited to a rating of one-half." Suppose that the butter has a slight wavy color and is slightly gritty: These defects would have a total rating of $1\frac{1}{2}$ points, or 1 point in excess of that allowed for 93 Score butter. The official score of the sample would therefore be U. S. 92 Score. In 1943, the Food Distribution Administration issued revised grade standards in which 91 Score was eliminated and letters were substituted for numbers. See Volume I, page 424.

Butter that is below the requirements of U. S. 85 Score because of its flavor or other conditions or because of excessive defects in body, color and/or salt is classified as "No-Grade." The following flavors and conditions in butter are in themselves sufficient to cause it to be so classed: in flavors—pronouncedly fishy, surface taint, limburger, tallowy, rancid, paint or varnish, gasoline, kerosene, or fly spray, chemical; in conditions—mold, grains of sand, splinters of wood, specks of rust, other foreign materials.

Only butter which grades 93 or 92 may be termed "fancy." Certificates of quality may be placed on cartons of 92 or 93 Score butter if the grade has been determined by an authorized representative of the F. D. A. The certificates show the score and the date it was issued.

Fresh Fruits and Vegetables.—U. S. Standards have been developed for most of the fresh fruits and vegetables now on the market. The grade terminology is in most cases very simple, with U. S. No. 1 as the top grade, U. S. No. 2 as the next grade, etc. U. S. No. 1 is always intended to include the major portion of the commodity that has customarily met the requirements of the best commercial grade, but a premium grade, "U. S. Fancy," is sometimes provided for products of exceptional quality. Certain other grades are also applied to some quality groupings which are of importance commercially. For example, "U. S. Extra No. 1 peaches" represent a quality equivalent to "U. S. No. 1 peaches" in all respects except that it has superior color (not less than 50%, by count, of the peaches must meet the requirements of color for "U. S. Fancy" peaches). Two or more standards are necessary for some products because of differences in types and uses. Hence, there are standards for bunched carrots and topped carrots; Bermuda onions, Creole onions, and Northern Grown onions; cabbage and cabbage for sauerkraut; tomatoes and tomatoes for strained tomato products. Grades are based upon the characteristics of each particular commodity, and specifications may vary considerably. In general, however, specifications for grades relate principally to variety, maturity, condition, shape, development, color, size, and defects.

Grades for fresh fruits and vegetables cannot easily be carried through to the consumer because grade identification is designed only for large quantities in wholesale trade. Grades are sometimes marked on quantities which are purchased by the ultimate consumer, as bags of potatoes and crates of fresh fruits. However, all fruits and vegetables are perishable to a greater or lesser degree and are subject to damage during transportation. To be absolutely certain of the accuracy of the grades of the foods in retail trade, it would be necessary for the retailer to have the grading performed on his premises. For the most part, it would be necessary to regrade all products which had been formerly graded by the producer or wholesaler. Since such a practice would necessarily add materially to the selling price of the fruits and vegetables, it is doubtful whether the consumer would be willing to pay the premium for graded products. When foods are sold in bulk, the consumer generally picks out what he believes to be the best specimens of the lot, and, in a measure, accomplishes his own grading. A retailer could not display a grade in connection

with a bulk supply of food and be certain that the supply would remain of the same grade after being picked over by a number of customers. While it is doubtful that grade labeling of fruits and vegetables for the retail market will ever be practiced on a wide scale, it is probable that it will be used to a greater extent than at present. Grade labeling will be accomplished when the demand for it is great enough and practical methods can be devised to overcome the difficulties involved.

Canned Fruits and Vegetables.—The grading of canned fruits and vegetables is relatively new, the first standards appearing in 1933. Since that time, grades have been developed for over 40 canned foods. In most cases, the grade terminology is simple and uniform. The grades are generally Grade A (*Fancy*), Grade B (*Choice*), Grade C (*Standard*), and Substandard or Off-Grade. For about 20 products, specifications have been set for all grades, but for about an equal number specifications are given only for Grade A, Grade C and Substandard. The various grades are described as follows by the F. D. A.¹⁴

Grade A (Fancy).—Only the finest canned fruits and vegetables are in this grade. They are carefully selected as to size, color, degree of maturity, and freedom from blemishes. The fruits are meaty, highly colored, and ripe. They are almost always packed in sirup, which may be extra heavy (very sweet), heavy (sweet), light (somewhat sweet), or in water, slightly sweetened. For certain purposes, the fruit may be packed in water without any sweetening. Grade A canned vegetables are the most tender and succulent produced.

Grade B (Choice).—The products in Grade B are of excellent quality, though not quite so well selected as to color, size, and maturity as Grade A products. Grade B canned fruits are well developed and well colored, and are packed in sirup or water as described for Grade A. Grade B canned vegetables are not quite so succulent and tender as those of Grade A.

Grade C (Standard).—Products in Grade C are of good quality but are not so uniform in color, size, and maturity as Grade B products. Grade C canned fruit may not be so highly colored, or so carefully selected as to size and symmetry, and though mature may vary somewhat in ripeness. The fruit may be packed in sirup or water. Grade C vegetables in some cases may have more food value than either Grade A or B as they usually are more fully mature than the products in the higher grades.

Below Grade C in Quality.—Some canned fruits and vegetables that fail to meet the requirements of Grade C in certain respects may be wholesome, nutritious, and acceptable in flavor, and if labeled to meet regulations for such foods as established under the Federal Food, Drug, and Cosmetic Act, may be sold on the retail market.

The standards for grades of canned tomatoes is a typical example of a grade description of canned vegetables, and shows the trend toward eliminating the factors subject to the personal element in grading. "U. S. Grade A" canned tomatoes are defined as tomatoes which have a drained weight of not less than 66% of the capacity of the can of which 80% are whole or almost whole, are of good red color, are practically free of defects, and possess a normal flavor. None of the factors may score below the grade description of A. The factors involved are drained weight, wholeness, color, and absence of defects. *Drained weight* is determined by weighing the tomato meat remaining on a specified screen after draining two minutes; this score represents the amount of product packed in the can. *Wholeness* is an estimation of

¹⁴ "The A B C of Canned Fruit and Vegetable Labeling," U. S. Dept. Agr., Agricultural Marketing Administration, *Misc. Pub.* 460 (1941).

how well the tomatoes have retained their original form; this score indicates the care the processor used in peeling, coring, and packing the fruit. The maturity is a big factor: an overripe tomato would be difficult to handle without destroying its original contour or splitting open the seed cavities. *Color* is determined by comparison with color plate standards; color development indicates the maturity of the product at the time of canning. *Absence of defects* deals with the degree of care exercised in the removal of extraneous matter, tomato skin, core, and blemishes that would ordinarily be removed in the preparation of tomatoes for culinary use. "U. S. Grade B" and "U. S. Grade C" canned tomatoes are those which fail to meet the requirements for Grade A but have no factor scoring below B or C specifications, respectively. Products in each grade must be of normal flavor but may have less drained weight, may be in somewhat smaller pieces, may show greater color variation, and may possess slightly more defects than those in the next higher grade.

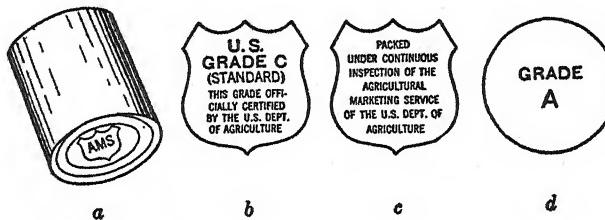


Fig. 1.—Typical grade labeling of canned fruits and vegetables.

The A. M. S. began an experiment of "continuous factory inspection" in 1939. Since that time, a number of canners have, during one or more canning seasons, operated under the supervision of inspectors of the F. D. A. The inspectors observe all operations in the plant from the time of the purchase of raw materials to the final canning of the finished product, and examine and certify the grade of each batch. Products which have been packed under continuous inspection may be identified by the shield stamped on one end of the can (or blown into the bottom of glass containers) but such identification (Fig. 1a) does not indicate the grade of the product. If the manufacturer so desires, he may label the product with the grade and indicate that it was packed under continuous inspection (Fig. 1b and 1c). Grades may also be stated on the label of products not under continuous inspection; but in such case the term "U. S." may not be employed nor may the shields be used (*e. g.*, Fig. 1 d), and the responsibility for establishing the true grade of the product falls wholly on the manufacturer.

Other Foods.—Grades have been established for a number of food commodities other than those which we have considered. Some of the products which are now graded by United States Grades are cheese, tuna fish, dried fruits, nuts, honey, and maple sirup. Within the last few years, grades have been set up for fresh frozen fruits and vegetables; and, since this industry is only in its infancy, we can expect

that grades for frozen products will hold an important place among the new grades and standards which are constantly being worked out.

(b) Grade Simplification

In addition to the development of new grades, we can expect that some of the grades which are in use are likely to be simplified or otherwise changed as time goes on. The recent changes made in the grading of beef to provide a simpler terminology for consumer use is a good example of the present trend. The increasing demand for graded foods is resulting in a much wider use of the grading services of the F. D. A.; and there is an ever-increasing tendency toward more grade labeling of consumer products. The consumer wants more and simpler grades. When his demands become sufficiently strong, the trade interests will undoubtedly be willing to give up their varied systems of grading and adopt "A, B, C" or "1, 2, 3" systems in favor of uniformity and simplicity.

Conditions existing in time of war have always had considerable effect upon all peacetime industries. This is true of food industries as much as any others. At the present time, many plants have increased production far beyond the point which would have been deemed possible in time of peace. New foods (particularly in the dehydrated line) are being rapidly developed for use by civilians and by the armed forces. So, too, are rationing and price-fixing regulations affecting food merchandising. The Office of Price Administration, as a part of the program to prevent inflation, has established price ceilings on a number of foods. In order to establish practical maximum prices for any food commodity it is necessary to take into consideration the various degrees of quality. Hence, ceiling prices have been, and will continue to be, set up with adequate consideration of the grade of the product. It is necessary for a dealer to establish the grade of his product in order to calculate ceiling prices. Whether or not it shall become necessary for the government to require that all food be sold by grade and labeled with the grade whenever possible, price-fixing regulations will result in greater use of uniform grades and will hasten the day when quality grades are commonly employed in retail as well as wholesale trade.

(c) Adopted Standards

Foods for which standards have been adopted are listed in the following table compiled by the Office of Food Standards Committee in February, 1943.

Food	Date published in <i>Federal Register</i>	Date effective
Apricots, canned		
Identity, quality, and fill of container.....	1/9/40	4/7/40
Amendment to identity (packing media).....	3/3/42	6/1/42
Labeling requirements for packing media 3 to 10, inclusive		2/26/43
Artichokes, canned		
Identity.....	2/28/40	5/27/40

Food	Date published in <i>Federal Register</i>	Date effective
Asparagus, canned		
Identity.....	2/28/40	5/27/40
Amendment.....	6/28/40	9/26/40
Beans, canned		
Green beans, identity.....	2/28/40	5/27/40
Lima beans, identity.....	2/28/40	5/27/40
Shelled beans, identity.....	2/28/40	5/27/40
Wax beans, identity.....	2/28/40	5/27/40
Bean sprouts, canned		
Identity.....	2/28/40	5/27/40
Beet greens, canned		
Identity.....	2/28/40	5/27/40
Beets, canned		
Identity.....	2/28/40	5/27/40
Broccoli, canned		
Identity.....	2/28/40	5/27/40
Brussels sprouts, canned		
Identity.....	2/28/40	5/27/40
Butter (Act of Congress; S. R. A., F. D. C. 1.)		
Cabbage, canned		
Identity.....	2/28/40	5/27/40
Carrots, canned		
Identity.....	2/28/40	5/27/40
Cauliflower, canned		
Identity.....	2/28/40	5/27/40
Celery, canned		
Identity.....	2/28/40	5/27/40
Cheeses		
Cheddar, identity.....	1/9/41	4/9/41
Colby, identity.....	1/9/41	4/9/41
Cottage, identity*.....	12/23/42	3/24/43
Cream, identity*.....	12/23/42	3/24/43
Creamed cottage, identity*.....	12/23/42	3/24/43
Neufchateau, identity*.....	12/23/42	3/24/43
Washed curd, identity.....	1/9/41	4/9/41
* Effective date with respect to propionates postponed pending action after special hearing.....	1/19/43	
Cherries, canned		
Identity, quality, and fill of container.....	1/9/40	4/7/40
Identity, amended.....	6/28/40	9/26/40
Identity, amended (packing media).....	3/3/42	6/1/42
Labeling requirements for packing media 3 to 10, inclusive		2/26/43
Collards, canned		
Identity.....	2/28/40	5/27/40
Corn, canned		
Field, identity.....	2/28/40	5/27/40
Golden sweet, identity.....	2/28/40	5/27/40
White sweet, identity.....	2/28/40	5/27/40
Yellow sweet, identity.....	2/28/40	5/27/40

IV. FOOD GRADING CONTROL

Food	Date published in Federal Register	Date effective
Cracked wheat Identity.....	5/27/41	1/1/42
Creams Light, identity.....	7/2/40	9/30/40
Light, whipping, identity.....	7/2/40	9/30/40
Heavy, whipping, identity.....	7/2/40	9/30/40
Crushed wheat Identity.....	5/27/41	1/1/42
Dandelion greens, canned Identity.....	2/28/40	5/27/40
Eggs Dried, identity.....	7/20/39	1/1/40
Frozen, identity.....	7/20/39	1/1/40
Liquid, identity.....	7/20/39	1/1/40
Egg yolks Dried, identity.....	7/20/39	1/1/40
Frozen, identity.....	7/20/39	1/1/40
Farina*		
Plain, identity.....	5/27/41	1/1/42
Enriched, identity.....	5/27/41	1/1/42
Effective date of riboflavin requirement postponed.....	12/3/41	7/1/42
Further postponed.....	4/25/42	4/20/43
* Definitions and standards of identity set aside by C. C. A. 7th Circuit; matter now being reviewed by Supreme Court.		
Fill of container General methods for determining.....	7/18/39	1/1/40
Flours Flour, white flour, identity.....	5/27/41	1/1/42
Bromated flour, identity.....	5/27/41	1/1/42
Bromated whole wheat flour, identity.....	5/27/41	1/1/42
Durum flour, identity.....	5/27/41	1/1/42
Enriched flour,* identity.....	5/27/41	1/1/42
Enriched bromated flour,* identity.....	5/27/41	1/1/42
Enriched self-rising flour,* identity.....	5/27/41	1/1/42
Phosphated flour, identity.....	5/27/41	1/1/42
Self-rising flour, identity.....	5/27/41	1/1/42
Whole wheat flour, identity.....	5/27/51	1/1/42
Whole durum wheat flour, identity.....	5/27/41	1/1/42
* Effective date of riboflavin requirement postponed.....	12/3/41	7/1/42
Further postponed.....	4/25/42	4/20/43
Fruit butters Identity.....	9/5/40	12/4/40
Fruit cocktail, canned Identity.....	7/21/42	10/19/42
Amended.....	12/16/42	3/16/43
Packing medium (e)(1).....		8/1/43
Quality and fill of container.....	8/18/42	11/16/42
Fruit jellies Identity.....	9/5/40	12/4/40
Fruit preserves (jams) Identity.....	9/5/40	12/4/40

Food	Date published in <i>Federal Register</i>	Date effective
Kale, canned Identity.....	2/28/40	5/27/40
Milks		
Concentrated milk, identity.....	7/2/40	9/30/40
Dried skim milk, identity.....	7/12/40	10/10/40
Effective date postponed.....	10/11/40	1/7/41
Evaporated milk, identity.....	7/2/40	9/30/40
Effective date postponed.....	9/10/40	3/1/41
Sweetened condensed milk, identity.....	7/2/40	9/30/40
Mushrooms, canned Identity.....	2/28/40	5/27/40
Mustard greens, canned Identity.....	2/28/40	5/27/40
Okra, canned Identity.....	2/28/40	5/27/40
Oleomargarine Identity.....	6/7/41	9/5/41
Onions, canned Identity.....	2/28/40	5/27/40
Parsnips, canned Identity.....	2/28/40	5/27/40
Peaches, canned Identity, quality, and fill of container.....	12/22/39	3/18/40
Identity, amended (packing media).....	3/3/42	6/1/42
Labeling requirements for packing media 3 to 10, inclusive		2/26/43
Pears, canned Identity, quality, and fill of container.....	1/9/40	4/7/40
Identity, amended (packing media).....	3/3/42	6/1/42
Labeling requirements for packing media 3 to 10, inclusive		2/26/43
Peas, canned Black-eyed peas, identity.....	2/28/40	5/27/40
Field peas, identity.....	2/28/40	5/27/40
Sweet peas, identity, quality, and fill of container.....	2/24/40	5/23/40
Identity amended to recognize Blair process.....	12/1/40	3/1/43
Peppers, canned Green sweet peppers, identity.....	2/28/40	5/27/40
Red sweet peppers, identity.....	2/28/40	5/27/40
Pimientos, canned Identity.....	2/28/40	5/27/40
Potatoes, canned Irish, identity.....	2/28/40	5/27/40
Sweet, identity.....	2/28/40	5/27/40
Rutabagas, canned Identity.....	2/28/40	5/27/40
Salsify, canned Identity.....	2/28/40	5/27/40
Semolina Identity.....	5/27/41	1/1/42
Shrimp, canned Fill of container.....	7/2/42	8/1/42
Special dietary foods Label statements.....	11/22/41	5/18/42

IV. FOOD GRADING CONTROL

Food	Date published in <i>Federal Register</i>	Date effective
Spinach, canned Identity.....	2/28/40	5/27/40
Substandard quality and fill of container General statements.....	7/18/39	1/1/40
Swiss chard, canned Identity.....	2/28/40	5/27/40
Tomato catsup Identity.....	7/29/39	1/1/40
Tomato juice, canned Identity.....	7/29/39	1/1/40
Tomato paste Identity.....	7/18/39	1/1/40
Tomato puree Identity.....	7/18/39	1/1/40
Tomatoes, canned Identity, quality, and fill of container.....	7/18/39	1/1/40
	Identity, amended (calcium chloride recognized as an optional ingredient).....	6/19/40
Truffles, canned Identity.....	2/28/40	5/27/40
Turnip greens, canned Identity.....	2/28/40	5/27/40
Turnips, canned Identity.....	2/28/40	5/27/40

Chapter V

FOOD MACHINES

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I. INTRODUCTION

The great social changes of recent times which centralized a great part of human activity in urban areas have made a profound change in our food situation. The moving of masses of people within the past 75 to 100 years to cities which became densely populated increased the food demand in these localities tremendously. This demand on the output of the local baker or other food purveyor could not have been fulfilled but for machines. If only manual labor were available as was formerly the case, the cost of production of food would not be in keeping with the cost of production of other goods being made in the new industrial era by machine. The machine in the food industry is responsible for more food of improved quality at lower cost, and can be credited with making available the means to preserve foods out of season for our tables all year round.

The purpose of this discussion is the examination of some of the problems food machines present to the food industry. It seems regrettable that so many machines excellently designed and constructed for mass production should have been made with so little regard for sanitary maintenance. Sanitary problems in food machinery present two important phases which must be discussed: the basic sanitary principles of design and construction; and the prevention of loss in production rate.

Sanitarians, particularly those engaged in dairy work, recognized these principles many years ago. Their success in quality control has been attributed to well-designed and well-constructed dairy machinery. The dairy industry learned the hard way, by trial and error. It has, however, developed certain fundamental rules in design and construction of milk equipment, and has had the happy experience of seeing good design and clever machine engineering reflect itself in lower bacteria counts in the finished product. It has had the great satisfaction of improving the taste and flavor of its products, and has also in turn been rewarded with greater popular acceptance of them.

* It is to be expressly understood that none of the opinions stated or implied in this chapter are to be considered as representing the official policies of the Department of Health of the City of New York.

Many food products are not so perishable as milk. Some foods are not good media for the growth of microorganisms. Food generally is not regulated by food laws in the same way as dairy products, especially with respect to bacterial count. These facts, nevertheless, should not lessen the interest of the food manufacturer in quality control. While legal bacterial standards do not exist for bread and many other foods, the food manufacturer must not relax his vigilance because mold, spoilage organisms, and other contaminants are ever present. Sliced bread which becomes moldy in the consumer's household has its serious effects on sales, yet apparently clean machines may have been the cause of this condition. There is also a very disastrous consequence to sales and prestige when ugly, hard masses or foreign materials which appear in food products might have been averted by clean machines and by cleaning made easy by proper design. Microscopic examinations of specimens of matter found accumulated around shaft bearings in mixers, from the interstices formed by adjoining parts of machinery, from piston heads of stuffers and depositing machines, and from other parts of food equipment within the product zone of apparently clean machines have exhibited filth, and fermented, decomposed material mixed with lubricating grease, worn metal particles, and salts of copper and nickel, as well as living organisms. With the aid of a low-power microscope a plant manager or food technologist can demonstrate the importance of proper equipment construction as a measure to prevent food contamination and food spoilage. By this means he can also evaluate the efficiency of his cleanup operation. As seen through the microscope, scrapings from machine parts within the product zone spread thinly on a slide are revealing and often alarming.

For the discussion of food machines there are some fundamental processes common to the manufacture of many kinds of food products. They include: cleaning of ingredients; grading and sorting; mixing and blending; cutting and grinding; pumping and conveying; and heating or refrigeration. In addition, there are others specific for the product, such as homogenization; filtration and clarification; separation; and coating and dipping.

This chapter will limit itself to machines used after the processes of cleaning the ingredients are completed. The importance of preventing any possibility of contamination from that point on is manifest.

II. PRINCIPLES OF SANITARY EQUIPMENT DESIGN

The food equipment used for grinding meat differs very slightly from that of the peanut grinder used in peanut butter making. The dough mixer in the bakery is essentially the same as the mixer in the Bologna kitchen except that the latter may sometimes be of the type known as a vacuum mixer because the machine may be tightly sealed so that air can be exhausted. The machines used in milk drying can, with slight modifications, be employed in egg drying. The principles of good design in a meat grinder may be applied to similar grinders regardless of the food product it helps produce. If machines are of similar design, similar essential principles of sanitary construction prevail.

The following is an outline of the principles of sanitary equipment design which have been found practical and satisfactory.

(1) *Dead ends*.—Dead ends are unused tapped holes, cracks, pitted castings, or other spaces which make cleaning of the machine difficult because food particles cannot be readily dislodged from these inaccessible openings. These should be avoided and eliminated as noted below.

(2) *Open seams*.—Open seams formed by adjoining machine parts often create an opening in which food materials accumulate. These joints are also difficult to clean. From a practical standpoint, good design can overcome this difficulty by making the junction outside the product zone. The alteration of older machines requires welding of the seams formed, sealing the seams with a pure tin gasket or pure tin solder, or the use, as a temporary expedient, of some suitable noninjurious cement. Smooth welding is preferred to all other methods in general use.

(3) *Solder and babbitt*.—Solder containing in excess of 5% of lead should not be used to seal seams or join parts of equipment in the product zone. The metals used for coving corners or closing seams or for other purposes within the product zone should not be harmful. Alloys containing a large proportion of lead or antimony or coatings or plating of cadmium are not recommended in any part of a food machine, especially within the product zone. In this same connection, it is a good rule to remember to use no metal which, when in contact with food, may form harmful compounds or toxic substances.

(4) *Smooth surfaces*.—All parts of a food machine within the product zone should be of smooth construction and of noncorrosive material. In describing the construction of machines, it cannot be stressed too frequently that certain surfaces of food equipment lie within the product zone and come in direct contact with food. These surfaces or parts should be machined, a term used to imply that the machined surface or part should be free of cracks, crevices, pits, holes, or other defects which would make cleaning and maintenance difficult.

(5) *Rounded corners*.—All junctions and corners should be rounded or coved.

(6) *Accessibility of parts*.—All parts of the product zone should be accessible, so that each part can be reached by a hand brush. In long, closed conveyors and chutes removable panels, conveniently spaced, are recommended.

(7) *Easy dismantling*.—All parts of a food machine which lie within the product zone or come in contact with food should be so constructed as to be easily dismantled for cleaning, examination, and repair.

(8) *Protection against lubricants*.—Means should be provided for the protection of the food product against contamination by lubricants and condensates.

(9) *Protection against droppings*.—There should be protection against outside contamination by sufficient overlap on covers or lids, with necessary complementary channels to carry off liquids, dust, or other material that may drop into the machine when lids or covers are raised.

(10) *Agitators*.—Agitator paddles or blades, unless they are one piece with the shaft or welded to the shaft, should be removable. Agitator shafts should be removable

from the power shaft at a point outside the product zone of the machine. Where the use of a suspended agitator is feasible, it is recommended because it eliminates the use of a stuffing box and other methods of sealing the shaft opening. The removable shaft arrangement permits complete and easy cleaning of the entire shaft, especially the part which passes through the stuffing box or rotary seal.

(11) *Stuffing boxes.*—Stuffing boxes should be accessible for examination and cleaning. The use of felt, leather, cotton, or other similar material is not desirable. A properly designed rotary seal should be used.

(12) *Pipe fittings.*—All fittings, valves, unions, and piping, except high-pressure pipe, should be of the standard sanitary type employing I.A.M.D. (International Association of Milk Dealers) standard thread. The valves should be of a plug type. All parts should be easily dismantled.

(13) *Threaded parts.*—No threaded parts of food equipment should be inaccessible for cleaning. There should be no inside threads.

(14) *Removable coupling nuts.*—Coupling nuts or unions on piping or valves should be installed so there is sufficient clearance, equal to three times the width of the nut, or should be especially constructed to be removable or come apart.

(15) *Threaded stud and wing nut assembly.*—Whenever possible a threaded stud and wing nut should be used in place of a tapped hole and bolt in the assembly of parts which are to be dismantled.

(16) *Runoff valve installation.*—Especially on jacketed kettles, the runoff valve should be installed as close to the kettle drain port as possible.

(17) *Use of wooden parts.*—The use of wood or other porous material is not recommended for food equipment.

(18) *Air filters.*—Air lines should be provided with filtering devices.

(19) *Screens.*—Screens and sieves should be made of perforated metal wherever possible.

(20) *Pistons.*—Pistons or plungers should be smoothly machined and fitted with metal rings so that they are effective without the use of rubber, leather, or wooden rings.

(21) *Submerged inlets.*—Water inlets should not be submerged or installed below the rim of any food container such as a kettle, tank, or trough. Where such an inlet is necessary for the proper functioning of the machine, suitable and adequate safeguards should be installed in the form of approved vacuum breakers and check valves. Vacuum breakers should be located at least four inches above the rim of the container or machine; and the check valve between the vacuum breaker and the water supplied machine.

(22) *Indirect waste.*—Waste from machines should not discharge directly to the sewage system.

(23) *Proper machine placing.*—All machines should be installed and placed so that no part is inaccessible for cleaning. The machine should be placed so that there is free and ready access around it for cleaning, inspection, and repair.

the sanitary or public health standpoint is not possible within the limits of this chapter, nor is there any real need for such exhaustive coverage. Comment will be made on the sanitary principles underlying the construction of typical food equipment and especially those machines that are extensively used in food manufacture.

III. SIMPLE EQUIPMENT

The basic principles of sanitary construction apply as much to simple equipment as to more complex food machines. Axiomatic as this may be, the most obvious defects in construction are everyday occurrences. The following are given as cases in point.

1. Knives

The knife made from a steel blade bound between two wooden grips to form its handle is one of the greatest violators of the sanitary rules of construction. The spatula or bowl knife, the improvised scraper for cleaning the abdominal cavity of fish, and other instruments with similarly constructed handles are most difficult to clean. They come in direct and intimate contact with food. Because of their construction, they contribute to soiling the hand of the operator when slight hand pressure tends to exude liquid or semiliquid materials lodged in the loose cracks of the handle parts. Among butchers and fish preservers, knives are often used having a grip implemented by winding cord around the handle. See Fig. 2, page 169. These knives are readily contaminated. Cleaning them is impossible; and contamination of the hand and food is almost inevitable.

The remedy for such conditions is the replacement of such knives by those having a one-piece handle made of metal or of plastic and having several shallow grooves for a comfortable grip.

2. Vats and Tanks

While not generally recognized as food machines, installations such as brining and soaking tanks, vats and tank covers, and valves and plumbing are really a part of this study. Preliminary consideration of the proper design of these plant needs may overcome much of the grief poor equipment can cause. The fact that contamination of food is possible by contact with unclean equipment of this kind is too obvious for further discussion. The errors in construction of some types of this equipment will be considered.

Soaking and brining tanks or vats used in food processing are made of wood (such as open casks, barrels, or tierces), of sheet metal (usually galvanized iron, as in tanks), or of poured concrete vats.

(a) Barrels and Tierces

Wooden barrels with their numerous staves and grooved edge for the cover or head present a very difficult cleaning problem. This type of vessel should not be used for any food purpose except those instances in which the food is composed of ingredients

all of which are water soluble. Their wide use in meat curing, fish soaking or brining, and brining of fruit for glacé is contrary to good sanitary practice. The numerous pores of the wooden staves absorb fats and meat particles, which are not removed by ordinary washing. The wood becomes logged with bloody water and organic matter not soluble in water and, therefore, cannot easily be cleaned.

(b) *Metal Tanks*

Metal tanks for brining represent a considerable advance, although the metal used, chiefly galvanized iron, deteriorates fairly readily, exposing large areas of rough, irregular, rusty surfaces which are also difficult to clean. Metal tanks, however, are serviceable until extensive corrosion sets in, and when properly constructed should be easily maintained in a sanitary condition. Properly constructed, rust-resistant steel tanks have given excellent service.

(c) *Poured Concrete Vats*

Properly constructed, poured concrete brining and soaking vats are, in many respects, desirable. Except that they lack portability they meet most other needs. Their construction, however, should be carefully considered. All junctions formed by the bottom and sides should be well rounded or coved. The bottom of the vat at its lowest point should be six inches above the floor level and should pitch toward the drain port. The bottom and sides should be well troweled or cement-washed to assure a smooth finish. The vat should discharge from a port six inches above the floor over a valley drain, and should never be submerged in the valley drain or be directly connected to a sewer. This eliminates the danger of backing up of sewage to empty vats. Most brining vats are located in cellars. Many are constructed in refrigerated rooms. Contamination by dripping condensate from cellar or refrigerator walls is a possibility. The construction of shallow channels along the rear ledge of a battery of vats pitching toward a drain channel running forward will carry off any contaminating fluids which may otherwise discharge into the vats. A further safeguard against contamination is a channel on the side ledge of each vat draining forward so that the overflow of an adjoining vat is carried off. See Fig. 3, page 169. All water inlets to these vats should be located well above the rim of each vat so as not to be regarded as a hazard to the water supply.

There have been a number of installations of soapstone brining vats. These are prefabricated and may be easily installed by means of suitable bolts and cement. The parts are made so that the completed vat or battery of vats have coved corners and properly pitched bottoms.

(d) *Kettle and Vat Covers*

The recommended covers for kettles and vats are those made of two completely removable parts. The under side of any fixed portion of a cover accumulates the dried

splashings of the liquids stored, cooked, or processed in the vessel. The under side is most difficult to clean. A fixed cover section or bridge on a tank or vat is wholly unnecessary except as a footing for a vertical agitator when no other design is possible. The cover should be constructed so as to open on a pivot provided by a loose joint hinge or a rod and socket arrangement, or some other means, as a removable pin hinge. The space formed by the junction of all sections of the cover should be protected by a drip channel to catch condensate, dirt, or foreign material which may fall into the kettle on opening the cover.

(e) Valves

Drawoff valves under kettles, tanks, or other similar holding devices should be of sanitary construction designed to come apart easily, and machined so that all surfaces of the product zone are smooth and free of pits, blowholes, or cracks. The valve most generally used in the dairy industry, known as the plug valve, has been satisfactorily adopted by many food machine manufacturers. There are three varieties (see Fig. 4, page 170) of plug valves: the bored plug, the slotted plug, and the notched plug. An important consideration in the design of this valve is its assembly. The tapped hole, as shown in Fig. 5 (see page 170) is not recommended. In its stead the stud and wing nut assembly is preferred, in that it is so much easier to clean and keep clean.

Valves should be placed as close to the drain port as possible and be attached by a removable coupling nut, thus avoiding inside threads. The fitting in this case should be one of three types now in general use.

1. The split "hex," consisting of two parts of an hexagonal nut kept together for strength by a pair of studs and wing nuts as shown in Fig. 6 (see page 170).
2. The removable "hex" coupling formed in a "C" shape and consisting of an hexagonal nut with a section of the perimeter cut out equal to about one-third, or, if considered as a chord, approximately equal to 120° .
3. A removable "hex" coupling nut constructed so that a section of the shoulder is cut out equivalent to approximately 120° of the inner arc forming the shoulder.

3. Tables

The tables in any food processing, manufacturing, or packing plant should be of all-metal construction, preferably of rust-resisting steel, have smooth welded seams and metal legs with ball-shaped bottoms. Those tables used for cutting meat, filleting and cleaning fish, and cutting or cleaning poultry or similar material may be provided with a small, removable, hardwood cutting board. This board should be one piece if possible, and not so large that it cannot be cleaned or treated suitably so that it does not contribute to the contamination of food.

4. Trucks and Troughs

Fermentation and measuring troughs, meat trucks, or other similar large portable containers for food or food ingredients should be made of metal of welded seam con-

struction and have rounded or coved corners. Where, for added strength, construction requires large metal surfaces to be bent or stamped, these bends or imprints should be wide and rounded. If edges are beaded or rolled, they should be welded to close the space which results. An open, slightly rolled edge, however, will also give added strength, and can be kept clean easily.

5. Beaters

There are a great variety of beaters, among which are wire beaters or whips. There are many types of solid metal beaters designed for sponge or heavy batters.

The wire whips or beaters used in vertical mixers are the most difficult parts of equipment to clean. Their use places them in direct contact with such foods as custard mixes, meringue, "butter cream," bakers' pot cheese, whipped cream, mayonnaise, and scores of other mixtures that are hazardous in nature if contaminated and therefore are of greater significance from the public health standpoint. These beaters consist of one, two, or three metal rings through which a number of heavy-gage wire strips are attached by open bends to form a sphere or oval. This construction is used to facilitate repair and make the replacement of the wire possible. There are objections to this type of construction from a sanitary point of view. The solution is not readily apparent. If welded construction were used, some improvement would result. The sharp corners formed by the wires as they pass through the forming rings present numerous foci for contamination. Each of the very many corners will not be brushed clean during the cleaning process. This permits the accumulation of material, generally yellowish in color, which with time becomes brownish and flakes off into the food batches.

The hand beater with its wound wire handle presents the same difficult cleaning problem. See Fig. 7, page 171.

Other types of beaters, such as the flat beater or marshmallow, batter, or sponge beaters, should be made from a smoothly finished casting, free of pits and holes. In all beaters the slotted socket end should be drilled through so that a dirt pocket or dead end cannot be formed.

6. Shovels

In the meat industry particularly, shovels are used for the transfer of masses of meat from troughs or trucks to mixers and back to trucks. Pitchforks also find their place in food manufacture. Until they were demonstrated as unsanitary, these tools of the ordinary wooden handle variety were used. Metal handle shovels and forks have replaced many of the others. However, at the base of the handle certain open seams remain which may be overcome by welding or which should be filled in with metal. Then the entire shovel or fork should be dipped in pure tin. Treated in this manner, these tools will resist corrosion and rust spots, will be easy to clean and keep clean, and will give excellent service.

7. Pails

Pails, like troughs or other containers, should be free of open seams. The best construction is the one-piece pail. However, if the seams at the bottom and along the

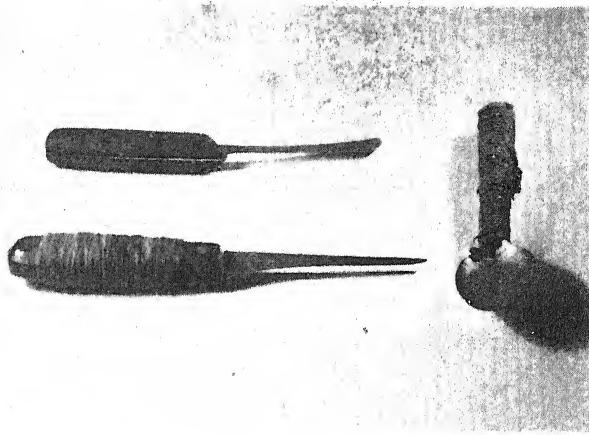


Fig. 2.—Knives showing unsanitary handle, improvised grip, and unsanitary cleaning scoop. (See page 165.)
(Photo by George Doherty, New York City.)

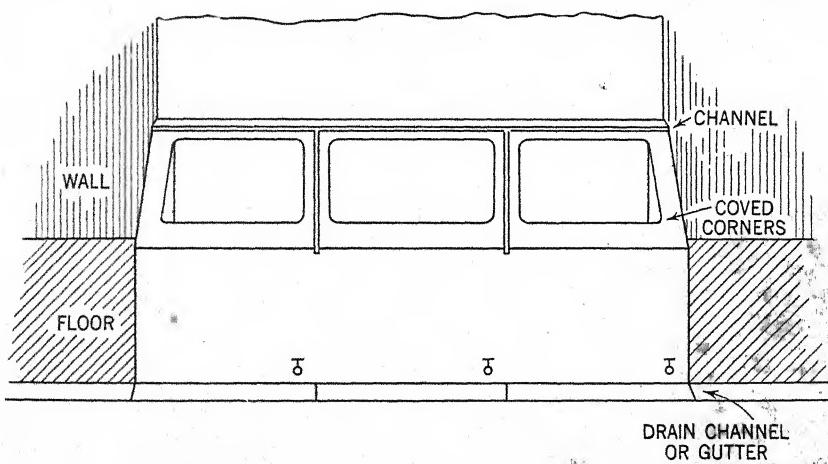


Fig. 3.—Drawing of a battery of poured concrete vats showing coved corners, drain, drain ports, and valves. (See page 166.)

pail body are closed by pure tin solder applied so that the seam is smooth, the pail should be quite satisfactory. The beaded rim of the pail should be closed by filling it

in with solder so that no open seam remains. The handle should be attached by means of a wide loop welded on to the pail body, so that at the point of junction no open space exists.

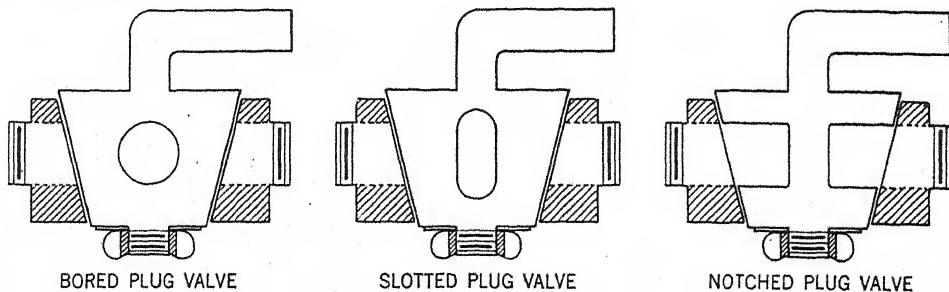


Fig. 4.—Diagrams of types of plug valves. (See page 167.)

8. Dippers

The use of dippers is to be discouraged. If a transfer of liquid in fair volume is necessary, the use of a portable sanitary pump is worth consideration.

A clean pump is labor saving, time saving and does not expose the food product to human handling. However, where a dipper is essential, it should be made of one-piece, all-metal construction. Otherwise the body and handle should be manufactured so that all seams are soldered smooth.

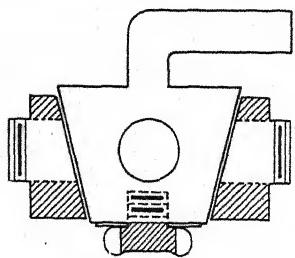


Fig. 5.—Diagram showing plug valve with dead end formed by the threaded hole and screw assembly. (See page 167.)

These few illustrations of the defects in design and construction, from the sanitary standpoint, of the more usual simple food equipment give ample evidence of the possibility of food contamination through their use if they are not thoroughly cleaned. The food equipment discussed, with the exception of the wire whipper and knife or scraper handle, can be kept clean with reasonable care and hard scrubbing. It does not, however,

seem justifiable to demand increased labor costs for cleanup and maintenance when design and construction can reduce this factor. Apart from labor cost, the food plant

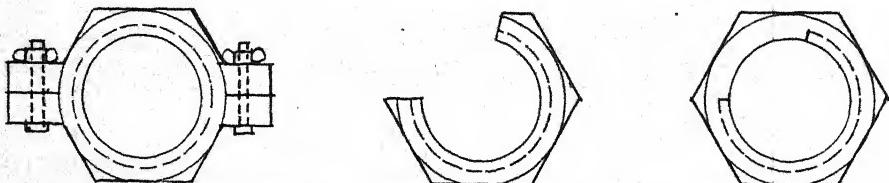


Fig. 6.—Diagrams of split coupling nuts. (See page 167.)

man must take into account the personal element of his plant crew, for each member of his cleanup crew has a different sanitary standard. Ease of cleaning removes all these probabilities.

IV. POWER EQUIPMENT

It has been shown that the unit operations such as grinding, mixing, etc., are common to the production of several food products. In a like manner, the machines which are used in these operations for different food products are the same, or are slightly modified. Therefore there is no need to analyze each machine within a given category and, as stated, this chapter will not include machinery used preparatory to processing, *i. e.*, sorting and grading equipment and cleaning and dehulling machines.

1. Mixing and Blending

Machinery has been designed and constructed to accomplish mixing of a wide variety of substances. The blending of liquids, powders, and semisolid masses, or the mixing of two or more materials of similar or different physical states, requires differently designed mixers.

(a) Liquids

Agitators.—The mixing of liquids, of liquid and powder, or of liquid and semisolids, so that the end product is a liquid, in an open vessel such as a kettle or vat, may well be accomplished by a portable or fixed suspended agitator. The agitator may consist of a long shaft upon which has been attached one or more propellers. This unit represents a simple cleaning problem, especially if the propellers are attached by set screws or are welded to the shaft so that there are no open seams. The propellers should be made of smooth metal with rounded corners. The shaft at the power end should be protected against lubrication drip.

The fixed suspended agitator may be one of two types. One consists of a power-driven shaft with one or more propellers attached, the agitator unit fixed to a bridge running diametrically across the top of the kettle, vat, or tank. The cleaning problem in this case would be greatly facilitated if the propeller shaft at the power end were removable at a point above the tank rim by a notched shaft and lock ring device or some other means which is fast operating and positive connecting. The second type con-

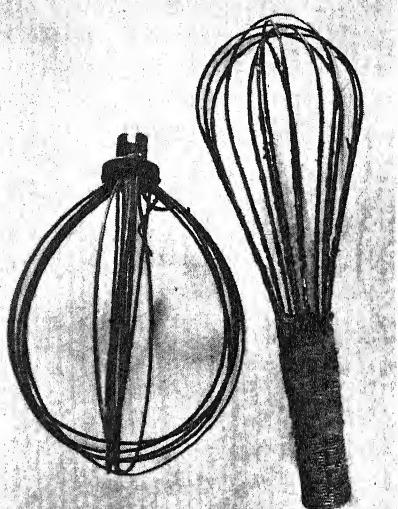


Fig. 7.—Unclean hand beater with unsanitary wound-wire handle, and unclean, broken machine beater with unsanitary socket (see page 168). (Photo by George Doherty, New York City.)

sists of a power-driven shaft with one or more propellers attached, but the agitator unit fixed to a movable part of the tank cover so that the agitator shaft is raised out of the tank when the cover is lifted. In this case the power end of the propeller shaft should be removable at a point above the top of the tank cover.

Submerged Agitator.—Propellers or agitators installed through the bottom or the side of tanks should be constructed of smooth metal, have rounded corners, and be connected to the shaft by welding. The shafts should be removable at a point outside the tank. The opening in the tank bottom or side which accommodates the shaft makes cleaning difficult unless an all-metal seal of the rotary seal type is provided. The use of packings of leather, cotton, felt, or other similar material makes the employment of a submerged agitator undesirable.

The Rotary Seal.—There are several types of rotary seal designs. Some are all-metal; others require a rubber ring or sleeve for tension. However, each is easily disassembled completely, usually by the removal of one nut. The seal is obtained by the finely finished surface of a seal ring turning against the finely finished surface of the seal seat of the piece of equipment. Tension is provided in many ways. There must be adequate pressure on the seal ring against the seal seat.

As shown in Fig. 8, tension is increased by a take-up nut. This type of seal was designed for an agitator shaft of a milk tank but may be similarly employed in other tanks.

As shown in Fig. 9, a rubber or Neoprene friction ring followed by a metal washer and spring gives the necessary tension against the seal ring and seat to accomplish sealing of the shaft opening.

As shown in Fig. 10, sealing is accomplished by a carbon seal ring against a seat welded around the shaft opening of the piece of machinery. Tension is sustained by a rubber sleeve (rubber tubing) pressing against the carbon seal ring and a fixed stop washer pinned to the shaft. The seal ring and the other parts turn with the shaft against a stationary seal seat.

Shaft Assembly.—As previously mentioned, the shaft of a submerged agitator should be removable. It should be broken at a point outside the tank. It should be notched and locked by a key, pin, or slip ring arrangement or connected by some other fast operating method. This can be readily accomplished. There will be no loss of power through transmission.

(b) Powders

The mixing of powders may be accomplished by various machines differently designed and named. There are the blenders, sifters, and mixers, each achieving the intimate mixing of powders. Because of the physical nature of powder the same consideration of sanitary safeguards is not required. Dry powders do not readily favor the growth of organisms of the pathogenic or food spoilage types. The principal problem is with the stored grain pest, the eggs, pupae, and larvae (weevil, worm, and moth), of the various species which are commonly associated with stored flour and

other similar material. Therefore powder mixers should be made of smooth metal, designed so that all parts are accessible for cleaning and inspection. Long chutes, elevators, and conveyors should be provided with clean-out panels conveniently located so that all interior parts are within arm's length of the clean-out opening.

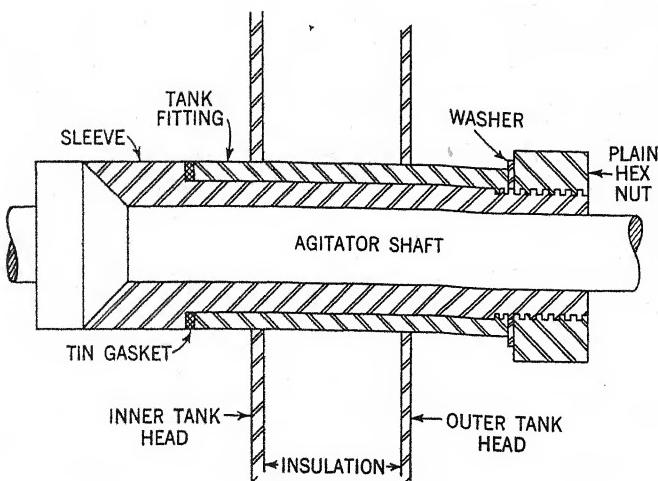


Fig. 8.—Drawing of all-metal rotary seal installed in a tank for a submerged agitator shaft. Packless type beveled seat agitator fitting. (Courtesy Alloy Products Corp., Waukesha, Wis.)

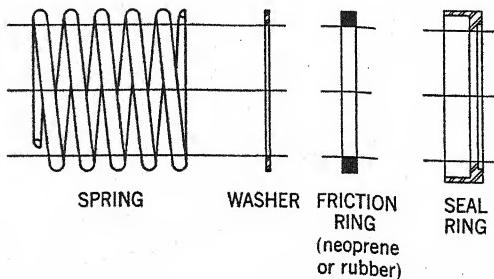


Fig. 9.—Rotary seal employing rubber ring for friction. (Courtesy Rotary Seal Co., Chicago, Ill.)

These mixers can best be cleaned by some dust collector operated on a vacuum cleaner principle.

There are many types of mixers. Those most commonly used are described in the following paragraphs.

Rotary Screen.—This consists of a drum made of perforated metal screening. The drum revolves slowly in a vertical plane. Running horizontally with the length of the drum and sometimes parallel to the axis are several baffle bars which carry the powder above the axis of the drum so that in falling some agitation is accomplished. The powder is introduced in the batch-size mixer when the drum is stationary through a sliding or hinged door on the circumference of the drum. In the continuous mixer, powder is supplied through a tubular opening which functions also as an axle for the revolving drum.

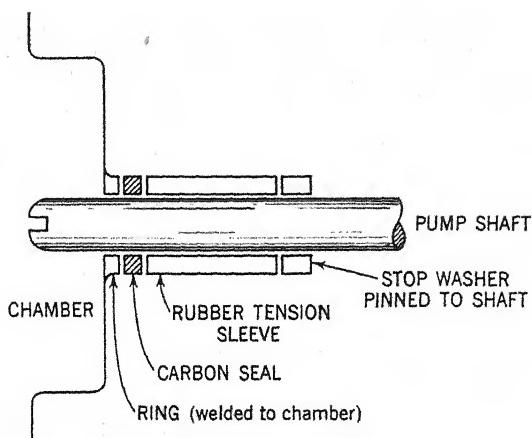


Fig. 10.—Rotary seal eliminating spring employing carbon seal. (Courtesy Cherry-Burrell Corp., Chicago, Ill.)

Stationary Screen.—This type of mixer consists of a stationary screen which is cylindrical or parabolic in shape. Agitation is achieved by the rotation of a set of brushes or blades. This kind of mixer can be continuous if provided with a hopper for feeding powders and a worm conveyor at the outlet for removal of mixed powders.

Rotary Cone.—The principle involved in this type of operation is not materially different from those previously mentioned. The present type of cone mixers involves both stationary or revolving cone-shaped screens with brushes or blades revolving therein. Where both cone and brushes revolve, the motion of the one is in the opposite direction to the other.

Multiple Screen.—This type of mixer consists of two or more flat screen trays made of metal or wire mesh with differently sized perforations. These trays are superimposed one over the other so that the coarser screen is above the finer. The screens are mechanically rocked or vibrated so that mixing and sifting is accomplished. This type of mixer can be continuous. The trays are easily removable for cleaning, inspection, and repair.

The foregoing types of powder mixing result also in sifting and blending. There are machines of different design which do not employ screens and naturally do not sift. Among them are those consisting of a deep, parabola-shaped bowl with a slowly revolving single-ribbon spiral carrying the powder in one direction or the double spiral carrying the powder forward and back. Then there is the mixer consisting of a shallow, steel, box-shaped container in which two rows of agitation paddles revolve. The paddles are so pitched as to give mixing and continuous conveying action.

(c) Semisolid and Plastic Masses

The machines to be considered in this group, extensively employed in the meat and baking industries, consist of a smooth steel bowl, shaped like a parabola, in which a strong steel agitator of varying design revolves. The bowl usually is made of two heavy steel-plate end pieces welded to a steel sheet forming the bowl bottom and sides. Riveting is objectionable unless the rivets are ground flush with the metal bowl and the crevices which are formed are filled in. The entire bowl is hung on heavy trunnions and is equipped with a tilting device. In many instances the bowl is jacketed for cooling or heating as required.

Meat Mixer.—This machine consists of a bowl similar to that described, but differs in that the bottom is raised at the center to form two distinct pockets. There are usually two rows of agitating paddles, each revolving in its own part of the sectioned bottom.

The construction or design of the meat mixer merits the following comment. Each row of paddles has two end paddles, set close to the end walls of the bowl. Unless a clearance of $\frac{3}{8}$ in. is made, this portion of the mixer cannot be adequately cleaned. By cutting sufficient metal off the paddle hub and part of the paddle blade (about $\frac{3}{8}$ in. \times $1\frac{1}{2}$ in.), clearance at the ends of the paddle shafts may be obtained (see Fig. 11) for the sanitation of the machine. The paddles are set and kept in place by bolts. There is consequently an undesirable clearance between the paddle shaft and inner surface of the paddle hub. This clearance should be sealed by a suitable cement which is not harmful. It is essential to have rounded or coved corners at points where the bowl bottom and sides join the end plates. The paddle blades should have no sharp corners and should be machined smooth, free of pits, holes, and cracks.

In packing sausage meat, it is often desirable to remove as much air as possible. Therefore mixing *in vacuo* is carried out in machines of a design similar to those outlined, but built so that about 28 inches of vacuum may be applied through the employment of an airtight fitting lid and a vacuum pump. For the attachment of air lines, nipples and other fittings should be installed so that there are no inside threads

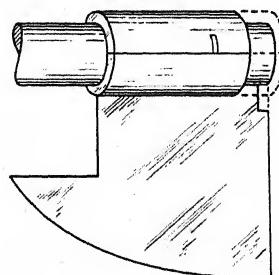


Fig. 11.—Diagram of detail of end paddle of meat mixer. Dotted lines indicate metal cut away to give clearance for cleaning.

in the lid. This is usually accomplished by welding a nipple to the lid rather than screwing the nipple into a threaded hole in the lid. The air inlet or vacuum release should be provided with some air filtering device.

Vertical Mixer.—The most widely used mixer, however, is the vertical mixer found in bakeries, and in mayonnaise, candy, and numerous other types of plants. This machine is used for less plastic masses, as for whipping butter and cream or making cake batters, meringue, salad dressing, mayonnaise, and similar mixtures. It has a variable speed control and an elevator platform upon which a deep bowl is set. This platform is raised or lowered by a crank actuating a gear and screw arrangement. There are a variety of beaters which may be used interchangeably in the mixer.

The vertical mixer is designed to give the beater motion in two planes. It may be considered to revolve on two axes, *i. e.*, it rotates on its own axis and while it revolves travels around the inner circumference of the bowl. As already pointed out on page 168, there is considerable danger that contamination can take place if the beater sockets are not drilled to overcome a dead end at the bottom of the socket. Care also should be exercised to see that lubricants do not drip into the bowl from the gear housing immediately above. The writer has on numerous occasions seen lubricating oil dripping down the beater shaft from the gear housing.

Giant vertical mixers are rapidly replacing the horizontal type in cake bakeries. These mixers employ a beater which is edged with heavy rubber. The rubber strip, when kept in place in the groove of the beater by a taut wire, results in a fold which is hard to keep clean. It has been recommended and successfully demonstrated that an edging can be used which consists of rubber moulded over heavy-gage wire. This rubber edging can be cemented into the beater groove and held by the encased wire kept taut by a take-up screw device.

2. Cutting and Grinding

An analysis of the types of operation employed in all food processing and manufacture will lead to the conclusion that the need of disintegration in the form of cutting and grinding is practically universal. In a discussion of cutting and grinding as an operation, no definite position can be assigned it as its place in the sequence of steps in food manufacture. For instance, in the early stages of bread making, machine cutting is performed when the dough is divided into pieces of given weight and then later again in slicing the finished loaf prior to wrapping. Similar instances can be found in the manufacture of other foods.

Disintegration, cutting, etc., are performed by many different machines in many ways. It is not intended in this section to analyze all grinders, cutters, mills, and similar disintegrating equipment, but rather to dwell on those that may contribute to food contamination by reason of their faulty design or construction. Many of these machines of similar design are used in various types of food processing with but slight modifications.

(a) *Grinders*

The grinder generally used in the food industry and exclusively in the meat industry is an outgrowth of the common meat grinder found in most household kitchens. Essentially, it consists of the body, a smooth metal casting which forms the rifled cylinder, and the whole or base of the hopper. Within the cylinder is placed a smooth-machined worm which revolves around a horizontal axis. Opposite the power end of this worm, a rotary, multiple-blade knife is installed, followed by a machined perforated plate. Thus far, except for the end plate, this type of construction represents no food contamination problem and a machine not difficult to clean. However, in motor-driven grinders, the power end of the worm fits into a power shaft housing. Unless a

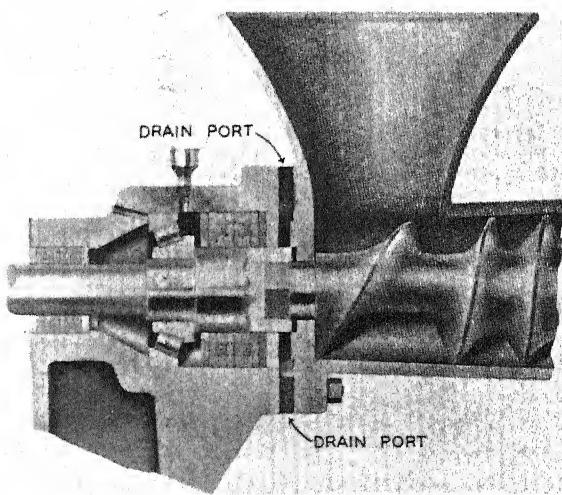


Fig. 12.—Sectional view of meat grinder showing flange drain port.
(Courtesy John E. Smith's Sons Co., Buffalo, N. Y.)

drain port is provided in the top and bottom of this shaft housing, a most disagreeable condition may result at this point. Here, meat juices, or juices or fluids extracted from other foods, and lubricating oil or grease may mix. See Fig. 12. Where the hopper of a grinder consists of sections added to the body casting, the sections should be easily removable. This may be accomplished by clamping the section to the hopper part of the body casting with wing nuts, clips, or some other similar arrangement.

The construction of this type of grinder just described has been modified for many and varied uses. Instead of a perforated end plate, a solid plate with a runoff port is provided for fruit juice extraction. See Fig. 13. By replacing the rotary, multiple-blade knife with a mill rotor and stator spaced for proper clearance, this grinder can be used for making nut paste, chiefly peanut butter. Whatever the modification or the use of the grinder, the parts should be easily removable for cleaning, and the drain port in

the power shaft housing should be provided. In the case of fruit juice extraction, much thought must be given to the kind of metal employed in the construction or the repair of the grinder or extractor so that no harmful metallic salts are formed by fruit or food acids acting upon machine parts.

(b) *Mills*

Many mills may be regarded as grinders. Most of these mills are designed for cracking or crushing of dry solid masses into fine powders. As in the case of powder mixers, the construction of mills or grinders in accordance with all the sanitary principles outlined would be ideal but would be not entirely practical. However, in mills used for

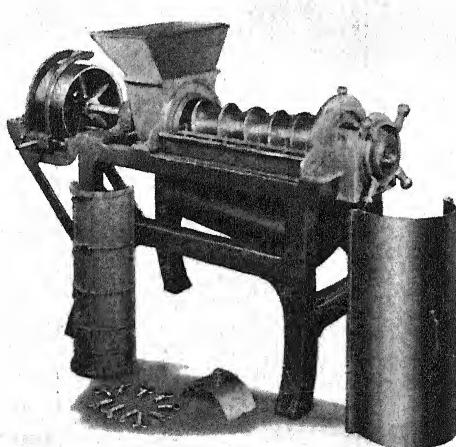


Fig. 13.—Juice extractor. (Courtesy Food Machinery Corp., Hoopeston, Ill.)

grinding ingredients to which liquids are added or which contain liquids, or oil, the application of proper sanitary design and construction is essential. Consequently, for completeness, the various mills will be described and the constructions of the colloid mills analyzed.

Hammer Mill.—This type of grinder consists of a hopper for a gravity or worm feed. The coarse, solid material is fed to a cutter plate machined to form a serrated or grooved surface. This plate is used to a point just below the axis and forms the upper portion of a parabola-shaped bowl. Within this bowl a number of hardened steel hammer arms rotate. They are carefully set for proper clearance to give the desired fineness to the product. The striking surfaces of each hammer arm are also serrated or grooved. The lower portion of the bowl is usually a removable steel screen the mesh or perforations of which are of the desired fineness. The action of this mill combines the striking of the hammer arms and grinding between the serrated

bowl plate and hammer surface. See Figs. 14 and 15. The mill is used for grinding such material as cocoa cake, spices, grain, and similar foodstuffs.

Attrition Mill.—This type of mill has been made with various modifications but consists essentially of a hopper for gravity feed or a worm feed and revolving steel cutting arrangements more fully described as follows:

Single Disk Grinder.—The solids are fed by gravity or worm into a gap formed by a vertical, revolving steel plate and the steel surface of the grinder body. Both surfaces

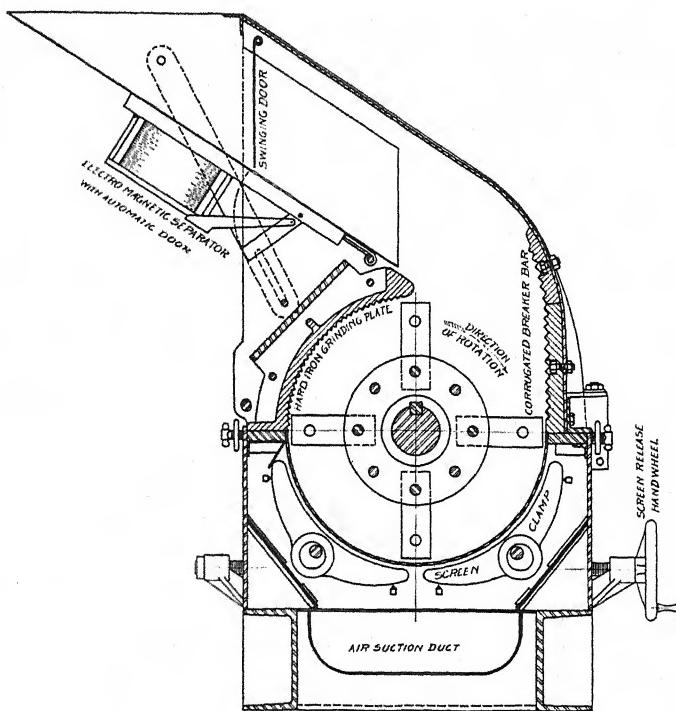


Fig. 14.—Sectional view of a hammer mill. (Courtesy Robinson Mfg. Co., Muncy, Pa.)

have sharp radial or helical grooves which perform the cutting when the plate rotates at high speed. The grinding gap is adjustable.

Double Disk Grinder.—This grinder is essentially the same as the single disk grinder except that both grinding surfaces are steel disks and revolve. The cutting surface of each disk is radial- or helical-grooved. The disks rotate in opposite directions at fair speed. The gap between plates is adjustable, to provide a desired fineness of cut.

Roller Grinder.—This type of mill consists of a hardened steel roller, machined so that it has many sharp grooves running spirally around the roller. The cutting is performed in a clearance between the roller and a rifled cylinder which forms part of the

body of the grinder. This rifled cylinder has grooves running opposite to those of the roller. The clearance is adjustable, to give a required fineness to the powdered product.

Other Mills.—There are other mills or crushers. Some disintegrate solid material by employing the principle of a coarse circular saw, while others effect grinding or crushing by concussion. Nevertheless, in these machines, as in others used for powder, there is no difficult cleaning problem and little danger of any harmful microbial contamination of food.

Colloid Mill.—The usual type of colloid mill consists of a smooth, metal hopper for gravity feed, placed over a smooth-machined metal rotor of a truncated cone shape. The rotor revolves at high speed within a stator machined to an angle com-

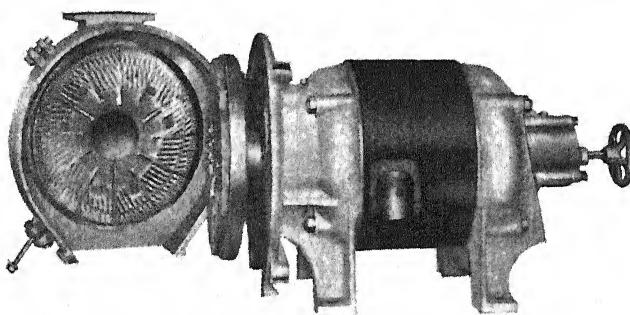


Fig. 15.—Disk grinder. (Courtesy Robinson Mfg. Co., Muncey, Pa.)

plementary to the rotor angle to form parallel operating surfaces. The gap between these surfaces is carefully fixed to a fraction of an inch, ranging from 0.001 to 0.05, depending upon the use to which the mill is to be put.

Many mills have a removable stator, thus exposing this part of the equipment and the rotor for cleaning. The rotors usually are not easily removable for cleaning. The machine is designed and constructed so that the carefully spaced gap is not disturbed. In many cases no provision is made for disassembling the rotor, particularly near its shaft bearing. Sanitary design dictates a break in the shaft at a point below the shaft housing. If this housing is within the product zone, the entire rotor shaft housing should be a smooth casting, free of pits and ground so corners are rounded or coved. The runoff or spillway below the rotor should be removable, smooth, and free of pits. Suitable precautions should be provided for protection against contamination from bearing lubricants. The hopper should be attached to the machine by flanges held in place by a wing nut and threaded stud assembly. The inside threads in the colloid mill frame and the corresponding outside threads on the hopper can be eliminated.

The embodiment of sanitary principles of design and construction in colloid mills is emphasized because liquid and semiliquid materials are treated in them. This type of

mill has been used to emulsify perishable food ingredients, as for the manufacture of mayonnaise and salad dressing and of fish, meat, nut, and vegetable pastes, for the crushing of fruit pulp in making fruit juices, and for many other foods.

(c) *Cutting Machines*

Silent Cutter.—In sausage making, after grinding, fine comminution takes place in an especially designed machine known as a silent cutter. This machine is also employed in other fields, as in cutting fish flesh and chopping vegetables. The silent cutter consists of a shallow bowl which is raised at the center, thus forming a circular pocket or ditch around the bowl. The bowl is made of smooth sheet steel and is set on a vertical shaft and is supported by roller bearings on the legs of the machine so that it may rotate in a horizontal plane. At one point over the bowl, an assembly of several sickle-shaped knives is installed. The knives revolve at high speed in a vertical plane within the pocket or ditch of the bowl. The clearance is carefully set at a fraction of an inch. The exposure of meat, fish, or other foods of a perishable nature to treatment of this kind is fraught with the danger of contamination. Rapid spoilage will be aided by the heat generated during the operation. This threat is amplified if sanitary precautions are not provided. The knife assembly consists of the rotating shaft, spacers, and blades which revolve in the slots of a metal comb. While desirable, it is not practical to recommend daily dismantling of the cutter assembly because the knives are very sharp and must be replaced with great care to obtain proper clearance. The comb should be easily removable so that there is easy access to the knife assembly. All surfaces of the comb and its slots should have no sharp corners and be machined, as they lie within the product zone. The knife assembly is shielded by a cast-iron, semicircular hood. The hood opens on a hinge. The inner and outer surfaces of the hood should be machined or ground smooth so that any accumulation of meat or other decomposable material is not harbored in pits, holes, and cracks. The machine is also provided with two plow blades. One blade, located on the left side of the machine near the shaft of the knife assembly, scrapes the meat or food material off the sides of the cutter bowl. It is essential that this blade be removable as well as adjustable. This plow, located as it is, is not accessible for cleaning and therefore should be easily dismantled. The second plow, also located on the left side of the machine, may be lowered into the bowl when cutting is completed. This plow blade pivots on two metal arms welded to the blade, which, when lowered into the bowl, accumulates behind it the comminuted meat or other food which has been distributed around the bowl during the cutting operation. This is done as the bowl rotates in a counterclockwise direction. The meat or food is collected so that the bowl may be emptied. The pivot arms should be welded on the surface of the plow blade which has no contact with food.

There are silent cutters which are self-emptying. In this type of machine, the raised center of the bowl is completely cut out. The hole which results is ground to form a seat for a conical-shaped, hollow, metal plug with a beveled edge.

This plug is raised by a lever when emptying is desired, and the plow blade simultaneously lowered. The plow blade directs the comminuted food to the center hole in the bowl from where it falls to a handtruck below. The plug should be made of well-finished smooth metal.

Cuber.—Cubers, or dicers, are devices for cutting food material into pieces of desired size, usually by the performance of two operations which may only be apparent as one. Food is passed through a set of rotating or vibrating blades which cut the food mass into long strips. When the food is passed into a second zone, rotating circular knives or vibrating blades operating at a right angle to the first set on the same plane or immediately below cut the strips into cubes.

The circular knife assembly should be completely disassembled for cleaning. Meat and other food particles and their juices seep between the blades and their spacers causing an undesirable condition. The finely slotted comb in which the blades rotate should be carefully machined, have no sharp corners, and also be easily removable for cleaning. The guides, push bar, catch pan, and chute should likewise be removable, and of smooth finished metal, with no sharp corners, dead end holes, protruding rivet heads, or countersunk screw heads.

Butter Cutter.—In the process of printing butter, the butter is first cut into pieces of a size which is suitable for the printing machine. The butter cutter is simple in design and construction. It consists of an all-metal table upon which rests the large slab of butter as removed from the tub or box. The butter is cut by a number of steel wires held taut in a rectangular metal frame which is raised and lowered by two geared arms attached to opposite sides of the frame. Power is transmitted to the cutter frame by a crank and gear arrangement at the side of the table. The sanitary observations which can be made in this case are as follows: The steel wires should be held taut by some fast operating and removable catch arrangement rather than by hooks attached to the frame so that wires, catches, and all of the cutter frame are removable for cleaning; and it should be possible to remove the geared arms from the cutter frame easily.

Slicers.—Bread and meat slicers are essentially similar in design and construction. They consist of a rotating circular knife or rotating set of sickle-shaped knives or a set of vibrating knife blades operating against a movable carriage which feeds the material to be cut to the moving knives. In the case of the circular knife, which is generally used for slicing bacon, or other meats, cheese, etc., the guard or housing which covers most of the blade should be easily removable for cleaning. Under it scraps of meat, fat, or cheese soon collect. The material to be sliced is held in place on the carriage by a plate which has many protruding sharp pins. This plate should be machined smooth and should be readily removable.

Dough Dividers.—In the making of rolls or buns, dough is quickly divided into pieces of equal given weight by the dough divider. This machine consists of a circular, pan-shaped receptacle into which a pressure plate fits tightly. The pressure plate has numerous slots through which knife blades may pass. The blade slots are distributed in the pressure head so that they cut pieces of equal volume. The blades

fit tightly in the pressure head. A piece of dough is placed in the receptacle. The lid is clamped closed, and the pressure plate forced up by a lever so that the dough is evenly spread in the receptacle. The knives are then released by a trigger, thus cutting the dough into equal portions. Experience has shown that dough can be forced past the pressure plate both at its circumference and between the knife blade slots in the pressure head, an undesirable condition being thereby created when the dough accumulates in the space beneath the pressure head.

As described for other machinery, grinders, mills, and cutters should be built with much regard for the sanitary principle outlined in each case. The objectionable conditions pointed out and the suggestions offered may not be all-inclusive. For proper evaluation, however, of a particular device the schedule on pages 163 and 164 should be most helpful.

3. Pumping and Conveying

The conduct of many food processing plants would be a most unprofitable and impossible activity if satisfactory means had not been invented for the transfer of food material in the various physical states from one place, machine, or operation to another. The fact that fluids, solids, or semisolids can be stored in various parts of a food plant and supplied to grinders, mixers, kettles, packaging machines, or waiting trucks makes food manufacturing the great industry it now is.

(a) Liquids

Sanitary Piping.—In the dairy industry, the piping used to convey milk or milk products from tanks or other equipment to the various machines and devices needed for the proper processing of the product is taken down to the last piece after each eight-hour run. It is then cleaned and sterilized and reassembled for further use. This is an ideal condition, and the dairy industry has developed the means to arrive at this goal—their product demanded it. Other foods deserve no lower a standard. In the egg breaking industry, great strides are being made to adopt dairy standards, equipment, and technique. Other industries, such as baking and meat processing, are following along.

Sanitary metal piping is made in various sizes based on outside diameter. It is tubing made of stainless steel or nickel-steel alloys, or heavily tinned brass, finished smooth inside and out. It is used universally in dairy plants and must eventually find more general use in other industries. The writer has seen food products such as custard filling and liquid eggs, which are potentially dangerous from a public health standpoint, pumped through ordinary water pipes and controlled by common valves used in any water system. These pipes and valves were never taken down but were flushed with water for cleaning. See Fig. 16. The treatment of perishable foods in better equipment which may easily be cleaned and sterilized yields food products which do not spoil as readily, which have no foreign flavor, and which look, taste, and are clean.

Sanitary metal piping should not be used in lengths exceeding ten feet and should be supported by hangers dropped from the ceiling. The various lengths should be coupled or joined by sanitary unions which, as shown in Fig. 17, consist of a threaded ferrule with a 45° ground seat, soldered or welded to the outlet end of the pipe.

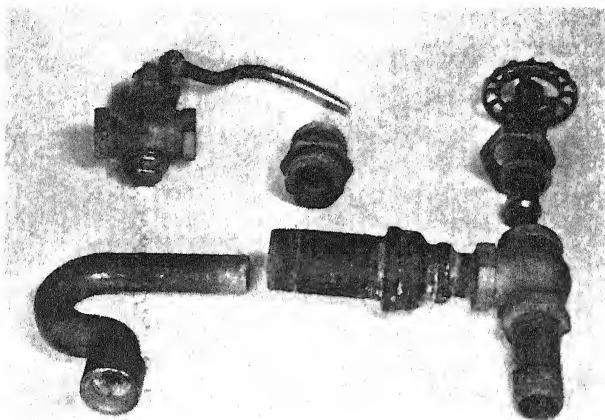


Fig. 16.—Piping taken from a custard filling line showing its unsanitary condition. Note heavy encrustation in piece on lower left. (Photo by George Doherty, New York City.)

A loose hexagonal nut is slipped on the other end of the pipe, followed by a plain recessless ferrule which is soldered or welded to the pipe. At the end of the ferrule is a 45° bevel which fits into the ground seat of a union or other fitting. The hexagonal nut with a smooth shoulder, fitting over the shoulder of the plain ferrule, takes up

on the threads of other fittings and thus makes a good leakproof joint. In some fittings, a single-service paper gasket may be used on the seat of the union or fitting. Thus easily removable, leakproof piping may be achieved. This piping may be attached to various devices such as tanks, valves, tees, ells, crosses, and pumps giving great versatility to this piping and conveying system.

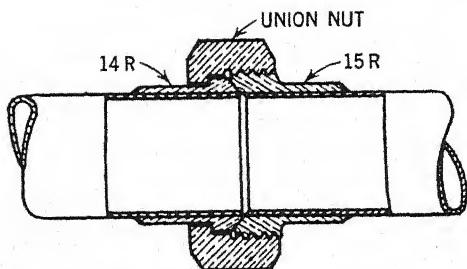


Fig. 17.—Drawing of a sanitary union fitting. (Courtesy Specialty Brass Co., Kenosha, Wis.)

affect metal. These installations were of the permanently fixed type. The lengths of tubing could not be removed readily from the piping system. Cleaning was done by flushing with water.

For many years the food and chemical industries have used glass piping and glass pumps for conveying material which may

The glass industry, however, probably stimulated by the critical shortage of metal attributed to the war, developed a glass which has all the characteristics of laboratory glassware and which may be used in place of sanitary metal piping and interchangeably with it and its many fittings. A technique has been developed to cut odd lengths of this glass tubing with suitable tools to desired sizes, bead the ends, and thus prepare them for service. The following method is used. Two adjustable uprights are provided, on top of which are two free rollers. The length of glass tubing is placed on these rollers so that it may revolve freely. Between the uprights is placed a diamond point scoring pencil also mounted on a similar upright having rollers. The glass tube is revolved after the scoring pencil has been brought to the glass at the point at which it is to be cut. A line around the tube is thus scored. A wire which is electrically heated is placed over the scored line. After thirty seconds of heat, a brush dipped in water is run across the line on the glass. The tube snaps into two lengths with a clean, square-cut end. The end of the desired length is then rotated slowly in an especially constructed gas- and oxygen-fired circular burner. When a bead forms at the end of the length, the pipe is rotated rapidly so that the bead is formed on the outer side. Following this procedure, the glass tube is heated over an ordinary gas burner to anneal it. For further information see *Journal of Milk Technology*, Sept.-Oct., 1942, pp. 303-304.

This glass tubing cannot be used until a specially moulded rubber gasket is fitted over the bead. A Bakelite or hard plastic, open follow ring is then installed over the glass tube at a point where a "hex" take-up nut (already described for other sanitary fittings on page 167) is brought down to make a union with another length of glass or sanitary metal tubing or any one of the numerous miscellaneous fittings used in sanitary installations.

The use of glass tubing in food plants has all the many advantages already attributed to sanitary metal piping, and is also transparent. While this is a sanitary advantage, it may be a technological disadvantage in products affected adversely by light. An installation of glass tubing where metal sanitary piping was formerly used will require that different hangers for holding pipe lengths be installed. For each horizontal length, two free swinging hangers are needed. For vertical lengths, solidly fixed hangers are urged. The caution necessary for the handling of this glass tubing is that it must be handled like similar glassware.

Pumps.—There are two general classes of pumps, both of which are used for food and milk transfer. The first general group consists of the positive displacement type; the other operates on the centrifugal principle. All these pumps have been developed to meet high sanitary standards. In the first group there are the following positive displacement types each of which is capable of developing high pressure: piston and valves; and rotary (gear, double rotor, and sliding blade valve). The second group consists of the various modifications of the centrifugal pump having an open or enclosed impeller.

Piston Pump.—The piston pump, as illustrated in Fig. 18, consists of a piston head and rod which slide back and forth within a horizontal cylinder, or up and down in a

vertical cylinder. The cylinder has an inlet and an outlet port. Each port is controlled by a valve operating in the direction of the flow. The piston is activated by a crank shaft or connecting rod. When the piston head is drawn to the end of the cylinder opposite the valves, the suction stroke takes place. The inlet valve opens by the unequal pressure on the valve. The fluid fills the space created in the cylinder. When the piston is forced back, the inlet valve closes by the pressure on the fluid in the cylinder, and by the same pressure the outlet valve opens. Thus the fluid is forced through the outlet port under pressure created by the piston during the discharge stroke. This process is then followed by the suction stroke, and thus pumping proceeds. The serious objections to piston pumps are:

1. They build up high pressure and may develop bursting pressure when the flow is stopped at the discharge end of the line.
2. The flow is pulsating.
3. Most packings used are porous and therefore present a serious sanitary problem.

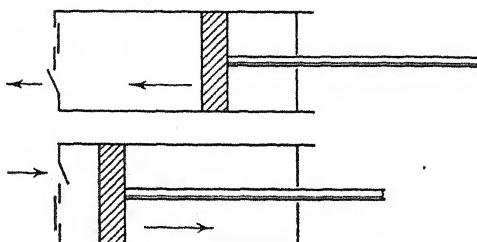


Fig. 18.—Diagram of piston pump. Top, showing pressure stroke; bottom, showing suction stroke.

These packings are made of leather, felt, cotton, or fabric combining asbestos and graphited cotton. They are used in stuffing boxes around piston rods to prevent leakage, and often are in contact with food or milk.

Rotary Pump.—This type of pump is positive acting by virtue of the displacement action of the gear teeth in the gear type, and of the crescent rotor in the double rotor type. Such pumps provide continuous flow under high pressure, and employ a rotary seal to prevent leakage at the drive shaft.

The *gear type* of pump consists of a nickel alloy or stainless-steel housing with an inlet and outlet port set at 90°. The inside surfaces are machined smooth so that an inside gear may revolve very close (a few thousandths of an inch) to the housing. The gear is cut so that the teeth are attached only on a back plate, that is, this gear may be visualized as a ring gear attached to a disk and then cut so that there are slots at the periphery between the teeth. This drive gear or rotor revolves a long tooth pinion installed within it but so that it rotates on an idling pin. The pin and a crescent-shaped metal fill (as shown on Fig. 19) are machined on a smooth, sanitary plate. This fill is formed to clear the arc of the pinion and inner arc of the rotor or drive gear.

The pump operates in either direction. Fluid is drawn in at the horizontal port when the rotor revolves counterclockwise. The spaces between teeth are filled with the fluid. When the teeth reach a point just before the outlet port, they mesh with the pinion. Each pinion tooth acts as a small piston displacing the fluid between the rotor teeth. The rotor and pinion teeth are completely meshed just before clearing the outlet port, thus forming a lock or valve preventing backflow and sustaining pressure.

The disadvantage of this type of pump is that it rotates at high speed for high pressure, and loses its efficiency when the clearance between moving parts becomes too great. The pump parts must be carefully handled to prevent nicks or dents which may injure its successful operation.

This pump is capable of transferring viscous material such as ice cream mix and partly frozen ice cream, heavy sirups containing fruit pulp or fruit particles, glucose, and other similar substances.

The double rotor pump is a positive rotary pump which operates at fair speed. It employs the displacement principle in a different fashion, so that each rotor in turn acts as a valve and piston. The pump consists of a nickel alloy or stainless-steel housing with the inlet and outlet port opposite each other in the hollow of the arcs formed by two overlapping circles. The housing casting is shaped like two overlapping circles. The inside is machined smooth so that two crescent-shaped rotors may revolve in opposite direction very close to the housing, as shown in Fig. 20.

Since the pump operates in either direction, either port may be the inlet or outlet. As shown in the diagram (Fig. 20a), the first quarter-turn reveals the upper rotor acting as a valve, while the forward end of the lower rotor forces fluid into the outlet. At the same time the back end creates suction action. In Fig. 20b, the next quarter-turn of both rotors brings the upper rotor in position so that the forward end is a piston forcing fluid to the outlet, while the back end is still in valve position at the inlet. However, the forward end of the lower rotor is now in valve position at the outlet, while the back end continues suction action. As shown in Fig. 20c, the upper rotor is now in pumping position at the forward end and in suction action at the back, while the lower rotor is acting as a valve at both ports. In the last quarter-turn (Fig. 20d) the forward end of the upper rotor is a valve at the outlet, while the back continues suction action. The lower rotor is in reverse position, *i. e.*, the forward end is pumping, while the back is in valve position at the inlet port. Thus the pumping is positive and continuous.

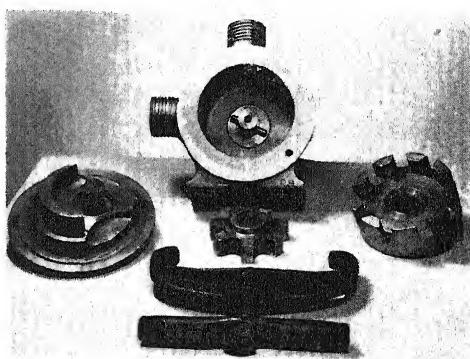


Fig. 19.—Positive type sanitary pump disassembled. Shaft seal not of newer rotary type. (Photograph by George Doherty, New York City.)

The efficiency of this pump depends upon the clearance between moving parts and decreases with wear. This is one of the most widely used pumps designed for general service in the food and milk industries.

The sliding blade valve pump, another rotary pump of the positive type, is used in the transfer of liquids and viscous materials. It employs sliding blades in the solid cylindrical rotor revolving off-center. The pump consists of a cylindrical body of nickel alloy or bronze carefully machined. Two ports are provided, either of which may be the inlet or outlet. They are set at an angle of 90° to each other but at a tangent to the internal circumference. The rotor is set off-center within the pump housing so that the circumference of the rotor has contact with the pump body at a point between the inlet and outlet ports. The rotor, which is a solid cylinder, has two narrow slots cut at right angles and running parallel to the axis of the cylinder. Two blades, especially cut out in the form of a square letter A, are set in these slots so that each has free movement. The blade is equal in width to the internal diameter of the pump housing.

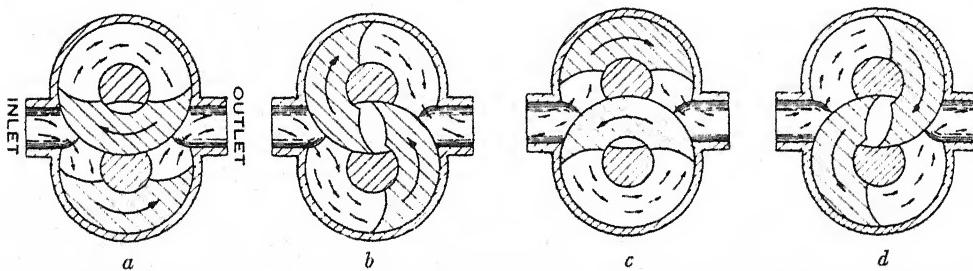


Fig. 20 (a-d).—Diagrams explaining the operation of the Bump Pump. (Courtesy Bump Pump Co., La Crosse, Wis.)

This pump can develop high pressure. It may be particularly useful for viscous materials. From a sanitary standpoint, the outer cover plate should be modified so that the rotor shaft housing is open. To prevent leaks, this opening may be capped by a ground seat plug and nut assembly so as to eliminate a dead end.

The positive pumps described should be designed and constructed so that:

1. The drive shaft is removable and broken at a point outside the pump housing.
2. The seal is of the sanitary rotary type or some other equally effective metal seal.
3. There are no sharp corners in the housing or pump parts which are inaccessible or hard to clean.
4. There are no threaded holes or dead ends in the housing or pump parts.
5. The pump can be easily disassembled.
6. Wing nut and threaded stud assembly can be used instead of screws and threaded holes.
7. There are no inside threads in the inlet or outlet ports.
8. Both ports have outside threads. However, if union nuts are needed on

either or both ports they can be of the split-nut type, if the clearance is not equal to three times the width of the nut.

Other Positive Pumps.—There are other types of positive pumps which employ the displacement principle in different ways. A pump has been introduced which consists of a section of rubber or Neoprene tubing in a metal housing. The pump functions by the action of an eccentric wheel which depresses the rubber tubing containing the fluid. This displacement provides the pumping action. Another type of pump consists of a vertical metal tube at the bottom of which a rubber helical cone or screw rotates. This spiral is connected to the end of a long drive shaft. The inlet port is at the bottom of the tube. The outlet may be an opening in the tube at a point above the spiral.

Centrifugal Type.—This type of pump, generally employing centrifugal force, is a high-speed pump which does not develop as high a pressure as the positive pump. The flow is continuous. However, this type of pump tends to churn fluids passing through it, a disadvantage and an undesirable feature in some stages of milk processing. The centrifugal pump has wide application in the pumping of fluids such as water, milk, sirup, oils, fruit juices, liquid eggs, and many other fluid food materials. It is simple in design and construction, and can be made in five simple parts: the housing or volute; its cover; the impeller; the removable drive shaft; and the rotary seal.

The housing is a smoothly machined casting of nickel alloy, tinned bronze or stainless steel. The pump chamber is usually circular in shape. The interior is smoothly finished, has no sharp corners, holes, pits, crevices, or cracks. It is drilled in the center to accommodate a shaft and a rotary seal. A short length of the outlet pipe of the pump is cast in the volute so that the center of the port is at a tangent to the inner circumference of the impeller chamber. The housing is closed by a plate which is smoothly machined. The pump inlet is cast as part of the pump plate and is in the center of it. The contact surfaces of the pump housing and plate are ground to form a tight seal, or machined to accommodate a rubber or single-service gasket. The two parts are held in place by a clamp arrangement or several threaded studs and wing nuts. See Fig. 21.

The impeller usually consists of a two-blade propeller or of three or more curved vanes radiating from the center. The impeller is drilled and notched at the center to accommodate a drive shaft. The metal used is similar to that of the pump housing. It also is machined smooth. The outer surfaces of some curved impeller vanes are hollowed so as to increase their volume or capacity. Some impellers are cast so that the vanes are attached to a disk. The latter type may still be recognized as an open impeller. However, there are some designs which consist of two parallel disks between which are curved tubular formations radiating from the center and representing the vanes of the open impeller. A modification of this is formed by a second disk on the open impeller. One of these disks is drilled so that several inlet ports are created near the center which connect with the tubes. The outlet ports of the enclosed impeller are at the periphery. There is some objection to the use of en-

closed impellers. It is clear that cleaning is difficult because the curved tubing is not readily accessible.

Both types of centrifugal pumps function so that a suction side is formed in the center of the rapidly revolving impeller. This point coincides with the inlet port of the pump housing plate. The impeller in motion moves the fluid at a point where there is no pressure offered by the tight confines of the impeller chamber or housing. This point coincides with the outlet port.

The drive shaft should be removable. It should be broken at a point outside the pump housing. To prevent leakage this shaft should pass through a rotary seal, such as described on page 172.

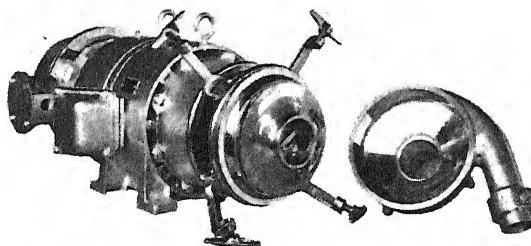


Fig. 21.—Impeller mounted on a disk. Open impeller type of centrifugal pump. (Courtesy Jensen Creamery Machinery Co., Bloomfield, N. J.)

Glass Pump.—There is now available a centrifugal pump made of laboratory glass and of the kind used for household baking ware. The volute and open impeller are glass. The drive shaft and other parts are of metal. This pump is not constructed in accordance with sanitary design principles herein outlined. However, its future development from a sanitary standpoint is not unlikely.

In the food industry, pumps are widely used. The pump is an integral part of the milk industry. The extension of the use of pumps to other phases of food processing is a matter of concern to every food technologist. An adequate and clean pump removes the risk of contamination present in dipping and transferring food material from one container to another.

Fittings (Valves).—Piping, and the fittings which make up a piping system, and pumps which force fluids through them require devices known as valves to regulate the rate of flow and the diversion of flow of a fluid. Valves have been discussed on page 167 in connection with drawing off fluids from tanks and kettles. A similar type of sanitary plug valve is used in piping systems to control and divert the flow of fluid.

As indicated in Fig. 22, a plug-type, straightway valve may be obtained which, when set in a pipe line, can be used to divert a flow in either of two directions by a quarter-turn. It can also be made to stop the flow completely by another quarter-turn; this valve is useful and has many applications.

A valve is shown in Fig. 23 which will permit a flow to two pipe lines simultaneously. It can also be used to fill two tanks at once or feed two bottling machines from one feed line. Yet it can control the flow by a quarter-turn so that either tank or machine may be cut off. By another quarter-turn the flow to both may be stopped. These valves are very versatile. They are simply constructed, having only three or four parts. They are made of tinned brass or bronze, nickel alloy, or stainless steel, and are machined smooth. All parts are accessible and readily removable for cleaning. They may be dismantled and reassembled in a few minutes, and can easily be removed from the pipe line completely and speedily.

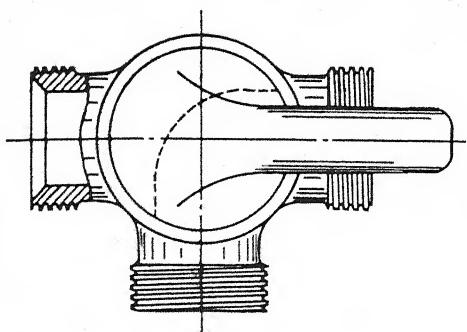


Fig. 22.—Plug valve for feeding one of two systems. (Courtesy Tri-Clover Machine Co., Kenosha, Wis.)

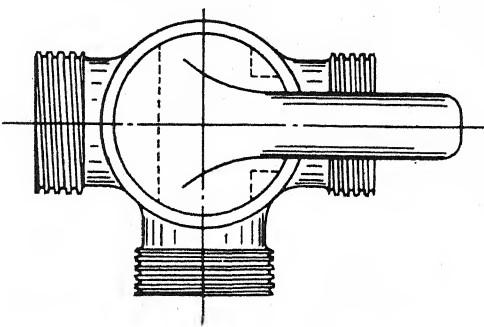


Fig. 23.—Plug valve for feeding two systems at once. (Courtesy Tri-Clover Machine Co., Kenosha, Wis.)

Other Fittings.—To lend versatility to a sanitary piping system, a full line of fittings has been designed and constructed. These are interchangeable as well as sanitary, and have been standardized by committees of the International Association of Milk Dealers, International Association of Milk Sanitarians, The Dairy Industries Supply Association and, lately, the International Association of Ice Cream Manufacturers. The standards adopted are known as I. A. M. D., or Three Association, or 3A, standards. They are not binding on anyone, although good business and manufacturing practice require adherence to them. The standardization of fittings permits the stocking of interchangeable parts and accessories and reduces the cost of this type of equipment, thus serving the best interests of all concerned—equipment manufacturers, users, and health authorities. A great deal of thought and careful study have been given the entire problem by these progressive organizations. The development of sanitary equipment which has been able to withstand searching bacteriological tests of the manufactured product speaks well for the efforts and achievement of the milk industry. It is unnecessary to repeat this work for other food industries. Since pumping and piping are similar in these industries, except where extremely high pressures are needed, much of the sanitary equipment developed by the milk industry can be utilized elsewhere.

The difficulty in cleaning the hexagonal take-up nut which is part of some fittings was outlined on page 167. It was recommended that such a nut be of the split type (see Fig. 6) where the clearance from the stem or ferrule shoulder to the body of the fitting is less than three times the width of the nut. It is practical to use fittings with threaded ends only. The take-up nut in such instances must be on the pipe length. This affords ample room for cleaning the shoulder of the nut and ferrule.

Sanitarians and plant men have recognized the importance of being able to see the interior of all parts of their equipment. The 90° ell for some time was an exception; but by the simple expedient of reducing the radius of the arc the so-called "clear vision" or No. 2 C ell has been developed. It is now possible to see all portions of the interior of this type of 90° ell fitting.

When used in a system of sanitary piping, these ell's, crosses, tees, Y's and valves with all ends threaded result in an ideal installation which facilitates cleaning and reflects itself favorably in the form of improved quality of production.

(b) *Semisolids*

The problem of conveying semisolids or plastic masses does not have a solution as universally applicable as the conduction of fluids through a closed pipe system. Neither are there means of conveying semisolids which are as versatile or interchangeable as sanitary piping. The other extreme, however, does not exist either—few conveying problems are so individual as to require their own peculiar solutions.

Conveyors.—The principal food product in the category of semisolids is bread dough. From a conveying standpoint, large production bakeries could not operate as efficiently as they do without a conveying system.

Cloth Pocket Conveyors.—After a dough is mixed, made, and proofed, it is punched in a dough mixer and fed to a divider where it is cut to proper size or weight. From the divider the dough pieces slide down a metal chute to a revolving spiral roller. The dough is rolled into a ball and formed, then deposited in a cloth pocket or metal pan by means of two metal fingers which pick it up from the roller table and raise it to the conveyor pockets. These cloth conveyor pockets or pans are connected like the fingers to an endless chain conveyor. Each piece of dough thus starts on a journey up and back for a predetermined period through the proof box which is regulated at a given temperature and humidity. See pages 521 and 522.

The cloth pocket of the conveyor presents a cleaning problem. The pores of the cloth soon become filled with dough particles; and after continued use the cloth therefore becomes discolored and foul smelling. The cloth pocket may be made removable if sewn to form a sleeve or with loops at opposite edges to fit over two round metal arms which are part of the endless chain. Many production men in bakeries prefer cloth pocket conveyors because they may be removed for cleaning and laundering. It is advantageous to use them because of the weight factor. Cloth pockets are lighter.

Metal Pan Conveyors.—There are other conveyors which utilize metal pans during

proofing. These pans fit into the conveyor chain and are removable for cleaning. The cleaning problem in this case may be more difficult, for metal pans are harder to handle and require individual cleaning.

(c) *Solids*

Conveyor Belts.—There are food processing operations which require the transfer of solid food materials from one point to another. In some cases this transfer is accomplished by conveyor belts which do not come in contact with the food, *i. e.*, they carry canned, jarred, or bottled material through various processes. The second kind of conveyor system, and the one having greater sanitary significance, has intimate contact with food. This type of conveyor is widely used in cooling freshly baked bread before slicing; in carrying formed print butter on its way to the wrapping machine, fresh fish fillets and eviscerated poultry to the packing table, candy centers through the chocolate enrober; and for many other food processing operations.

Several types of conveyor belts are employed.

The Continuous Canvas Belt.—This is made of heavy cloth in various widths, and operates over revolving end drums and rollers. It should be used principally for carrying dry materials. It can be cleaned only with great difficulty. For example, when used to convey bread from the oven through the cooler the belt absorbs shortening from the bottom of the hot loaves, and unless regularly cleaned develops a rancid fat odor. When used for conveying butter, a similar condition results more rapidly. Some ice cream specialty departments use canvas belts to carry a large square cracker upon which is placed a square brick of ice cream which is then covered by another square cracker to form a sandwich; this belt may absorb particles of melted ice cream which fall on it during the operation. A canvas belt used in direct contact with food cannot, therefore, be regarded as satisfactory from a sanitary point of view.

The canvas belt has been modified in some ways. An attempt was made to cover it with material which has a smooth, hard, waterproof, and nonabsorbent surface. Although such surfaces are satisfactory when new, constant bending and contact with foods develop cracks which tend to produce unclean conditions. Belts have been developed and used which have a rubber surface, and are satisfactory when the surface is intact. Many food materials, however, adversely affect these belts, causing cracks and deterioration of the rubber.

Metal Link Belts.—This type of endless chain can be made in many modifications. The links are closely meshed and operate over end sprockets and rollers. The links are forged in varying shapes so that a flat surface is formed when the chain is assembled. Although this kind of belt can be cleaned by hosing, there are some overlapping parts which are not accessible for cleaning and which, if they become unclean, may contaminate adjoining surfaces.

Conveyor Trays.—The chain or belt conducting individual small removable metal trays is a solution to the sanitary problem of conveying operations which involve fresh fish fillet, eviscerated poultry or poultry parts, sliced meats, or analogous foodstuffs.

Metal Belt.—The steel or stainless-steel metal belt with all seams welded smooth seems to be a good approach to the solution of conveying food materials through operations in which trays are too cumbersome or impractical. The walls of a tray would interfere, for example, in a cleaning operation in which a shower is employed that would tend to fill the tray, or after a heat-treating operation when it is necessary to scoop up the food treated. The endless metal belt affords a good opportunity to clean by hosing. Cleansing with chemicals is also possible with little danger of damage to equipment.

(d) *Powders and Granules*

There are two primary considerations in the problem of conveying powdered material, granules, or other small particles of food in a solid state: vertical transfer, and horizontal transfer.

Chain and Bucket.—For the transfer of powder by carrying it upward, a chain and bucket arrangement is used. Such a system consists of one or two endless chains running parallel over synchronized sprockets and free rollers. A bucket is hung on the chain or between both chains. This chain and bucket assembly operates within the confines of a rectangular chute of wood or metal construction. The powdered or granular material is concentrated in a shallow pit fed by a gravity chute or by a worm. Each bucket as it turns around the lower end sprocket slips into the pile of material, fills up and carries off a quantity of material to a higher elevation where a second end sprocket is installed. When rounding this, the bucket is tipped and the material is dumped to a hopper, pit, or chute.

Rotating Worm Conveyor.—The transfer of powder horizontally is accomplished principally by the action of a long rotating worm which operates within a rectangular or round wooden or metal chute. For powdered and granular material this type of worm conveyor is widely used. However, there is another type of conveyor which employs paddles set at a suitable angle so that conveying action results with the rotary motion of the paddles and shaft.

Pneumatic Conveying.—Pneumatic conveying is used for powdered or light solid materials.

In *horizontal conveying*, the powdered, granular, or flaky food material is fed to a shallow hopper at the end of which is installed a duct opening. The duct runs horizontally for a specified distance and terminates in a collector in which an exhaust fan operates.

In *vertical conveying*, powdered, granular, and flaky materials are fed, usually by a worm conveyor, to a perforated table over which a hood, duct, and exhaust fan are installed. The material to be transferred is drawn by air currents through metal ducts to a collector, which may be an inverted, cone-shaped metal chamber, or to numerous large cloth bags, or to an enclosed collector room the air outlet of which is screened by finely woven cloth to prevent solid particles from being carried off. The upward transfer of similar solid material may also be accomplished by feeding this material

by a worm conveyor into the top of an enclosed chamber and in an air current which is caused by an exhaust fan. The fan is located at the terminal end of the duct and collector system in a manner similar to those described above.

The equipment used for conveying dry materials such as powders, grain, or granular substances represents little hazard from a sanitary point of view. As mentioned on page 163, in order to overcome the economic losses caused by contamination by insect infestation, all parts of these conveyors should be easily and readily accessible for cleaning. The chutes should have removable panels conveniently located so that all internal parts of the conveyor are within reach at arm's length. The buckets and chains of the conveyor should be easily removable for regular and frequent cleaning.

4. Heating and Cooling

The proper transfer of heat in food processes is of utmost importance. It represents success or failure in the manufacture of a product from many points of view. Economically, insufficient heating may mean undercooking or faulty sterilization. This results in loss of sales or loss of merchandise by spoilage. From a public health standpoint, poor heat transfer may mean improper processing, as in precooked pork products with resultant danger of trichinosis transmission, in understerilization of nonacid canned goods with the danger of botulism, or in lack of sustained pasteurizing temperatures with the possibility of exposing great numbers of people to milk-borne diseases. Heat transfer involves also the loss of heat, as in cooling and refrigeration. See page 77. Here, there are also economic and public health factors which must be considered. The costs involved, in providing heat and refrigeration, may mean the making of a profit or sustaining of a loss. Proper application of the principles of heat transfer is important. The factors which effect heat transfer are:

1. Metal used for construction of equipment should be rated high for heat conductivity.
2. The metal used should be as thin as possible without sacrificing the strength necessary for the proper use of the equipment.
3. Agitation is necessary to prevent the formation of a film on the heat transfer wall, as well as to distribute the heated food product throughout the mass.
4. Whenever possible the principle of counterflow should be fully exploited.
5. As great a temperature differential as possible should be employed. The temperature should be consistent with the needs of the process and nature of the material, and should also be accurately controllable.

Modern methods of heat transfer do not employ the application of direct flame. The use of indirect methods offers greater control and efficiency. Equipment employing these methods will be described.

Efficient heat transfer devices have been developed for use in food and milk plants. Some of these will be examined from a sanitary point of view.

(a) Kettles

Kettles which have been properly jacketed so that an enclosed space exists around them, or which are surrounded by metal coils, may be used for cooking and cooling interchangeably if hot water or cold water or brine is pumped through the jacket or coil. This transfer of heat should be assisted by some means of mixing the mass in the kettle. The formation of film on the heat transfer surfaces should be prevented.

The installation of heating or cooling coils in the product zone of the kettles is not recommended. Such kettles are difficult to clean, and from the point of view of heat transfer are not efficient because the coils interfere with good mixing and offer no facility for the removal of an interfering film which may form on the coil. Jacketed and other temperature-controlled kettles should be constructed so that the runoff valve is as close to the outlet port as possible. A pipe running from the outlet port of the kettle with a valve at the end for convenience usually is equal in length to the radius of the kettle. The content of this pipe is raw or undercooked, and thus represents either an economic loss if wasted, or a hazard if the material must be cooked or chilled for bacterial control. The valve should be of sanitary construction. The agitator and other parts should be removable for cleaning.

(b) Rotating Coil Heat Exchangers

The rotating coil heat exchanger consists of a low, troughlike, insulated metal vat having a single or double spiral coil revolving in it. This coil serves as a heat exchanger and agitator. The disadvantages of this device are: its limited heat transfer surface and therefore its limited capacity; the difficulty of cleaning the coils and vat bottom; and the presence of two stuffing boxes by means of which the heat transfer coil or coils pass through the vat walls.

(c) Surface Type Heat Exchanger

Coils.—Heat is efficiently exchanged by the surface type of equipment by permitting a slow trickle of the fluid to be treated to flow in a thin film over coils through which brine or hot water is pumped. These coils should be constructed so that the space formed between pipe lengths are free of sharp corners and can be cleaned easily. See Figs. 24(a) and (b). The pipes should be of smooth metal, and, if the metal is one which may impart an off-flavor, should be tinned. The fluid to be treated is pumped to a trough at the top of the coil. The bottom of the trough is perforated so that the fluid drips over the coil to form a thin sheet which is collected in another trough at the bottom of the coil. From here it is pumped to further processes, to storage tanks, or to filling machines. The troughs should be made of smooth metal, should have all the sanitary characteristics heretofore advocated, and should be easily removable for cleaning. Large sheet-metal covers which hang on a roller and track arrangement protect the fluid from contamination by enclosing and concealing the entire unit, a type of unit which is compact as well as efficient.

Plates.—The most recent development in heat exchange devices is the plate type of heat exchanger. This also operates on the principle of exposing the fluid to large areas of the heat transfer surfaces. The device consists of numerous thin, stainless-

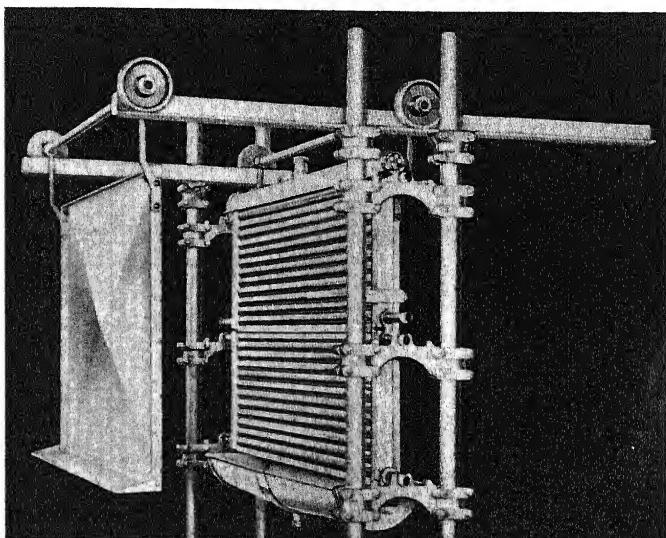


Fig. 24(a).—Surface type heat exchanger. (Courtesy Specialty Brass Co., Kenosha, Wis.)

steel sheets, each stamped in a pattern to provide a flow course. The fluid to be treated follows this flow course between two such plates, which are clamped together and made leakproof by a rubber gasket. Sets of plates are banked so that the fluid to be treated is contained within the two plates, while the heat transfer medium circulates around the outside of these plates but is also confined within similar plates on opposite sides. A film of fluid and a film of the heat transfer medium thus alternate to make up the unit. The amount of heat transfer surface required can be regulated by the operator, who may vary the number of plates as he wishes. The plates are arranged so that heat is exchanged by the counterflow principle, wherein the heat exchange medium is pumped in at the bottom of one set of plates while the fluid flows on the other side of the plate flows from the top down. In the next set of plates this flow direction is reversed.

There are some precautions involving pumping pressures which must be taken when using this type of heat exchanger. It is always desirable to have the higher pressure on

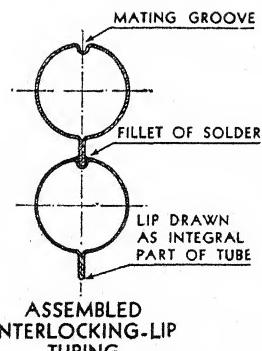


Fig. 24(b).—Diagram of tubing assembly. (Courtesy Specialty Brass Co., Kenosha, Wis.)

the fluid food being treated. Thus if there are any leaking gaskets the fluid foods would not be contaminated.

The plate heat exchanger may serve as a regenerator, that is, sections of it may be arranged for use as a preheater by utilizing the heat in the cooked material ready for cooling as a heat transfer medium flowing counter to cold raw fluid to be heat treated.

The plate type of heat exchanger can be cleaned easily. By opening the screw press the plates may be separated. The individual plate hangs on rods or on channel bars. While hanging in this position, each may be scrubbed and flushed by hosing. All fittings and pumps used in connection with this heat exchange equipment are of the sanitary type already described.

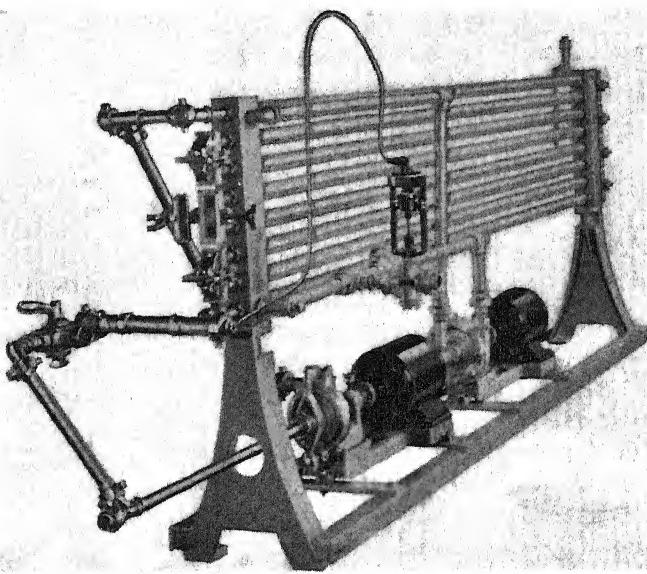


Fig. 25.—Inner tube heat exchanger. (Courtesy Specialty Brass Co., Kenosha, Wis.)

(d) *Inner Tube Heat Exchanger*

The inner tube heat exchanger consists of a series of special pipe lengths having an inner and outer pipe. The space in the inner pipe contains the fluid to be treated. The space formed between the inner and outer pipe carries the heat exchange medium flowing in the opposite direction. The inner pipes, as shown in Fig. 25, are open at the ends, with each length connected to the next by a hollowed plate which serves as a quick removable U. By this arrangement each pipe length may be thoroughly brushed and cleaned. The inner surface of the entire length of each pipe is visible and

therefore accessible for cleaning. The outer pipe lengths are connected to each other at a point a short distance from the end so that there is continuous flow. The heat transfer medium is usually pumped in at the bottom, the outlet being at the top of the unit. The fluid food to be heat treated is pumped in at the top, the outlet being at the bottom. Each length of pipe is pitched at a slight angle.

This type of heat exchanger, slightly modified so that there are two inner tubes, has been constructed and is in use in several food industries. This type increases capacity but is used for lower temperature purposes, principally as a preheater.

The double tube heat exchanger can also be used as a regenerator. This modification, however, involves sanitary inner and outer pipes and a differently designed end plate. The end plate in this case must have two parallel channels so that two U's are formed for the return of two pipe systems. Although this heat exchanger is a closed system and is efficient, it lacks the versatility of the plate type. This device should be equipped with sanitary fittings and pumps.

(e) Regenerators

With proper modification, some heat exchange devices, except the coil-type surface heater, may be used as regenerators. There are two types of regenerator hookups. One employs a second fluid for heat transfer, usually potable water. The other effects the transfer of heat from the hot processed product to the cold raw product through a heat-conducting metal wall which separates these fluids. These fluids on both sides of the separating wall of the tube or plate flow in opposite directions.

(f) Drum-Type Heat Exchanger

The vertical drum type, as well as the similar horizontal heat exchanger, such as the ice cream freezer, consists of a cylindrical, insulated metal chamber around which is provided space for a coil carrying the heat transfer medium. There is usually an agitating device within the cylinder which consists of several blades, some of which are sharp edged and designed so as to remove surface film from the cylinder walls. This device is useful for heavy and viscous materials. It has a limited heat transfer surface. Unless the agitator is completely removable and the scraper blades are easily disassembled, this kind of machine represents a difficult cleaning problem. In addition, it is essential that the drive shaft be removable at a point outside the cylinder wall, necessitating the use of a sanitary seal for the shaft opening.

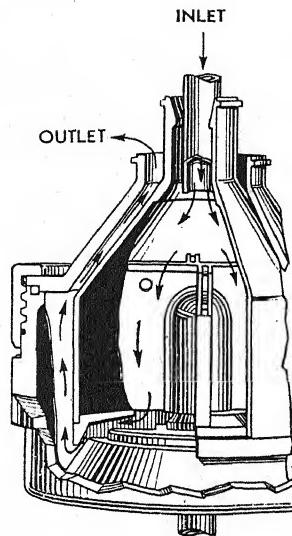


Fig. 26.—Cross section showing the construction of a centrifugal clarifier. Arrows show the flow of liquid through the bowl of the Multiple Clarifier, while the black masses indicate how dirt builds up in the two chambers (see page 206). (Courtesy DeLaval Separator Co., New York City.)

(g) Hot Water Sprays

In the meat industry, many operators prefer cooking frankfurts or similar sausage meats after smoking. This is frequently accomplished by means of a hot water spray used in the following manner. The tree or cage containing the many links of smoked

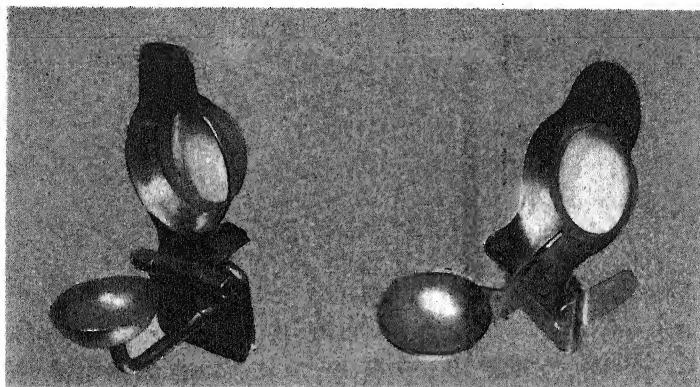


Fig. 27.—Photograph of two commonly used egg separators (see page 207). (Photograph by George Doherty, New York City.)

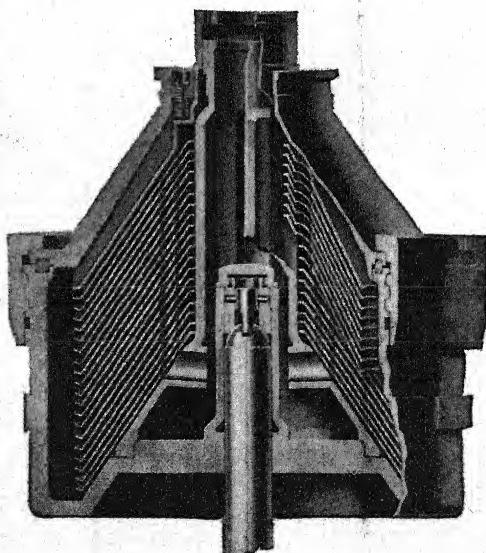


Fig. 28.—Cross section showing the construction of a centrifugal separator (see page 207). (Courtesy DeLaval Separator Co., New York City.)

sausage meat which hang over sticks or rods is rolled out of the smoke chamber by means of an overhead track and roller arrangement, into a chamber the top and sides of which are lined with numerous spray heads. When the doors of the chamber are closed, the spray pump is started which forces hot water through the spray heads onto the meat product. The water for this purpose is drawn from a shallow pan at the bottom of the chamber. The water temperature is maintained by a thermostatically controlled valve which permits the introduction of hot water as needed. Excess water is disposed by an overflow pipe installed in the pan.

From an efficiency standpoint, it must be said that this method of cooking makes great use of the heat that is supplied; the practice involves the recirculation of hot water. From the sanitary point of view, there is objection to the re-use of water which is sprayed on sausage meats, smoking sticks, trees, or cages and which runs off the inner walls of the spray chamber. This water has been found to contain fat, tarry matter, products of combustion, and miscellaneous foreign material. The pump used to supply the spray heads is not easy to disassemble for cleaning. The entire device may be altered by the simple expedient of laying a coil on the bottom of the pan, and thus using the hot water in the shallow well as a heat transfer medium to the water in the coil. This would be considered sanitary in that the spray heads would be supplying clean hot water for cooking purposes.

In this case, as in any other where coils are exposed, pipe lengths should be separated sufficiently to permit access between and around them for thorough cleaning.

(h) Steam Inlets

Often cooking is accomplished by the introduction of low-pressure steam into the material which is to be heat treated in the vat. This installation is efficient, but from a sanitary point of view represents the following objectionable features:

1. The steam inlet pipe is not easily removable for cleaning; and the perforated pipe opening into the kettle or vat may harbor food material which may serve as a medium for bacterial growth during periods when the steam valve is off.
2. The steam may carry over into a kettle many boiler impurities which are undesirable, such as boiler cleaner and antirust compounds and pipe and boiler scale, and may add water of condensation to the product if considerable steam is used.

5. Dehydration

There are many food products, such as bouillon cubes, breakfast foods, candy, eggs, gelatin, alimentary paste, malt extract, whole or skimmed milk powder, pectins, and a large variety of vegetables and fruits, which are treated with heat to remove free moisture. Many methods are employed and equipment of various kinds have been designed and constructed to facilitate this process. See pages 90 and 283. Heat sources vary from the use of solar rays to electricity, and include steam, hot air, and products of combustion as well as the direct flame.

(a) Drum Driers

This type of dehydrating device employs a large cylinder or drum, the inner surface of which is exposed to the heat of the direct flame or steam. The outer surface is smoothly machined. Fluid food material is deposited on this surface of the drum at a given point in several ways: A small part of the drum may *dip* into a pan of the fluid food, and the adhering food is spread to the desired thickness by a small heated roller. The drum is fed directly, by *gravity*, by means of a trough or perforated pipe from which the fluid food drips on to the drum at a predetermined rate, and is spread as a film on the drum by a small heated roller. Liquid food is *sprayed* on the drum, and is also spread in many instances to assure a uniform film. At a point on the drum sometimes as much as 300° from the feed, a knife blade is installed to remove by scraping the dried food now in the form of a thin crepe sheet.

The principal sanitary problem in connection with this type of equipment resides in the design and construction of the feed:

1. The pans used in the dip feed and the trough in the gravity feed should be made of smooth metal, which can be cleaned easily and which is not attacked or corroded by the material it may hold. There should be no open seams or dead ends in the pan or trough.
2. The perforated pipe should be removable for cleaning. It should also be made of metal or other material which is smooth and which, if in contact with foods, will not form harmful metallic salts.
3. The spray is applied by either of two methods: pressure nozzles, or a centrifugal spray wheel. The nozzle and strainer of the nozzle assembly represent a difficult cleaning problem. The orifices are of necessity extremely small. Frequent and complete disassembly followed by soaking in a suitable detergent solution is urged for cleaning. The change of nozzles in a continuous operation need not greatly interfere with production. The pressure necessary for good atomization is high and is usually accomplished by a piston pump similar to that which is described under homogenizers (see page 208). The centrifugal spray wheel should be constructed so that the rotor or disk feed can be easily removed for cleaning.
4. The knife blade or scraper on the drum drier should also be removable as well as adjustable.

(b) Rotary Driers

There are many driers, employing various modifications, based on the general principle of dehydrating food in a cylindrical chamber which rotates on a horizontal axis. This type of drier for continuous operation may be tilted. The pitch may determine the exposure time of the food to be heated. Most rotary driers have numerous narrow shelves or flights running parallel with the axis which carry the material to be dried to the top of the interior of the cylinder, from where it falls through a hot air current.

The great variation in the operating principle of this type of drier is the method of heat application to promote moisture evaporation:

1. Food comes in contact with the heated part of the machine.
 - (a) The exterior of the cylindrical drum may be heated by direct flame or by steam coils which may encircle it.
 - (b) Heat is supplied by products of combustion, by steam, or by hot air passing through a flue which runs through the center of the machine and parallel with the horizontal axis.
 - (c) Steam, hot air, or products of combustion pass through pipes or tubes, or ducts or flues lining the interior wall of the cylindrical chamber.
2. Food comes in contact with hot air currents. Filtered air is blown across a heated surface such as steam coils or radiators and then into the drying chamber. The food falls through this hot air current.
3. Evaporation is promoted by food in contact with a heated surface and hot air current.
 - (a) Hot air or gases pass through flues lining the interior or encircling the exterior walls of the cylinder, and then pass into the cylindrical chamber.
 - (b) Hot air or gases pass through a flue in the center of the cylinder and exhaust into the cylindrical chamber.

The sanitary aspects of the rotary driers have little public health significance. The food products which enter for drying are cleaned and blanched prior to the dehydrating process. The heated chamber is hot, usually above temperatures suitable for the growth of microorganisms. However, there should be no sharp corners at a junction of the flight or shelf and the inner wall of the cylinder. There should be no inaccessible spaces formed by steam tubes or flues which may impede inspection and cleaning. No metal, such as cadmium, should be used as a coating or plating which, when in contact with certain foods, may form harmful metallic salts. The air to be heated should pass through a filter.

(c) Cabinet Driers

The cabinet drier consists of a compartment made of wood or sheet metal, lined or covered with insulating material. This compartment may be small and built for a battery of trays, or large enough to hold one or more trucks with numerous trays stacked on them so that there is sufficient space between each tray to permit air passage. Each compartment has its air inlet and outlet. Some have an auxiliary blower, and some have baffles also to facilitate better air circulation and distribution.

The sanitary problems which merit consideration are those connected with the construction of the trays and the possibility of rodent harborage in cabinets so poorly constructed that this condition can exist. The trays should be all metal preferably. If the bottoms of these trays are not solid, then perforated bottoms are more desirable than wire mesh. The metal used should be one which will not be attacked by foods to form harmful metallic salts. Metal as well as wooden driers, unless constructed in

accordance with acceptable rodentproofing methods, may especially harbor rodents in the insulating material. The cabinet should be tied into the floor, preferably by a heavy-gage, wide, metal strip all around the base. The cabinet door should be edged with metal at the bottom to prevent gnawing at the door. Other vulnerable points should be similarly treated.

(d) *Vacuum Driers*

The drum, rotary, and cabinet driers have been further modified to operate under reduced pressure. These are similar to the driers already described. The drum drier is usually enclosed by a heavily constructed outer shell. The rotary drier is modified to the extent that the end walls of the chamber are sealed and the cylinder jacketed for hot water heating. The cabinet drier is constructed so that the wall can withstand reduced pressure while heating is accomplished by pumping hot water through hollow shelves and partitions.

(e) *Tunnel Driers*

This type of dehydrater can best be described as a long cabinet drier which can accommodate a number of trucks of trays. The trucks are moved along from the inlet to the outlet of the tunnel by a conveyor. The food product is dried by the time it reaches the outlet end. Drying may be carried out by air currents traveling in the direction of the trucks, opposite to the direction of travel; or the drying medium may be introduced by a flue to the middle of the tunnel and directed to both inlet and outlet sides. The sanitary requirements in the construction of this type of equipment are the same as in the cabinet drier.

(f) *Conveyor Driers*

This type of drier consists of one or more conveyor belts operating at a predetermined speed through a long tunnel. The belts may be arranged so that there are multiple passes around end pulleys, an arrangement permitting agitation of the product as it falls from one belt or pan to the one beneath. Hot air currents are circulated within the tunnel, aided by properly placed baffle plates.

The sanitary aspects which this type of conveyor presents are the hazards of the conveyor belt. The wire-mesh belt, canvas belt, and deteriorated and cracked leather belt are very difficult to clean. Pan types are good if the pans are removable. The belt to be preferred is the seamless, rust-resistant metal belt which can be scraped, washed, or hosed, as the case requires, for cleaning.

The limitations of this chapter do not permit detailed discussion of the various types of dehydraters, such as the one utilizing a rotary cylinder into which numerous tangential louvres open, and others.

V. SPECIFIC OPERATIONS

There are certain special processes that are used in specific types of food manufacture which require machines designed to meet these needs. In this group are such processes as filtration, clarification and separation, emulsification and homogenization, coating and enrobing. Many of the sanitary design and construction difficulties which have been encountered in other machines may be found in the machines used in these operations.

1. Filtration

There are many kinds of filters (see page 30) and clarifiers and filtering materials used. In some processes, filtration through paper is the most satisfactory one; others require cloth, sand, stone, activated carbon, diatomaceous earth, asbestos, or similar materials. The filtering material will naturally determine the design of the filter. However, the basic sanitary principles of construction prevail.

All filter frames for holding cloth and paper filters and retaining filter beds should be machined so that a smooth surface is offered to facilitate cleaning. In these frames a metal screen base is often provided to support the cloth or paper filter pad or bag or to form the foundation for the filter bed or cell. This base should be of perforated metal rather than woven-wire mesh. In the pressure type of filter, there is no option—a strong and often reinforced perforated metal base is used. The clamps or press of the filter should be designed to open easily. While there is little doubt that most filters will be cleaned frequently because they fail to function properly if dirty, frequent washing saves time and labor and promotes good plant practices. As in other equipment, piping to and from filters should be of the sanitary type and be connected with sanitary fittings. There should be no threaded holes for the inlet and outlet pipes of these filters.

In plants where water treatment by filtration is required, sand and stone filters are generally employed. These are usually cleaned by backwashing, a practice necessitating certain sanitary safeguards in the plumbing installation. The backwash outlet should not be connected directly with the sewer. The water inlet should be protected by some approved vacuum breaking device and check valve to prevent the backflow of filter contents if a temporary negative pressure exists in the water supply line.

2. Clarification

Clarification (see page 27) may be accomplished by centrifugal means. Some devices revolve a quantity of a fluid at high speed, the heavy sediment and clear liquid moving to different parts of the bowl in the machine and thus causing a physical separation.

The most widely used clarifier is similar in construction to the separator described on page 207, differing essentially in the construction of the rotor bowl. The bowl is bell-shaped, and consists of an inner and outer chamber. The chambers are incom-

pletely separated by a dropped wall and ledge which leaves an opening at the bottom of the bowl connecting both chambers. See Fig. 26, page 199. The heavy materials, sediment, dirt, or other foreign particles accumulate against the wall of the inner chamber to a thickness approximately equal to the width of the ledge when the machine is in operation. This condition reduces length of travel and the effectiveness of the centrifugal force of the machine in operation. Therefore, some sediment carries over with the liquid to the outer chamber where, because of greater travel, the mixture is treated with more active centrifugal force. The sediment thus removed accumulates against the wall of the outer chamber.

There is another type of clarifier bowl which also is a modification of the separator bowl. Like the separator rotor, it consists of numerous fins or disks, having but one orifice in each segment at the peripheral edge of the fin or disk. There is a space between the peripheral edge of the fins or disks and the wall of the bowl and space near the center. The sediment moves toward the outer space and is accumulated there. The clear fluid flows toward the center and upward along the outer wall of the inlet tube, overflowing the edge of the bowl into the receptacle formed by the clarifier cover. The sanitary maintenance connected with this device requires daily disassembly and thorough cleaning of the collection receptacles, the rotor bowl, and its parts and many fins. The drive shaft has no sanitary significance because it is not in the product zone. The fluid to be treated is confined in the rotor bowl and collection pans.

3. Separation

The equipment used in some separating (see page 25) processes for *solids* has been described in the section dealing with mixing and blending (see page 172). Some of these machines can be slightly modified or arranged to do either job. They employ perforated metal sheets or wire screens having meshes of various degrees of fineness. Thus the coarser powdered material may be separated from the finer.

In separating operations, such as in the sorting and grading of peas, long tapering drums are used which revolve around a horizontal axis. These are made of perforated metal, with the largest holes at one end and the smallest at the other. The holes between are graduated in size.

Finely powdered material or light solids may be separated from granular particles by pneumatic means, by several methods:

1. By blowing air through a bed of the material to be separated. The bed is formed by dumping and spreading the material to be treated upon a perforated screen or table over which a hood and metal duct and fan are installed. The light particles, such as dust, dirt, insect fragments, insect-bored grains or beans, flaky material, or other similar matter, may be blown or drawn out to an inverted cone-shaped or other type of collector.

2. By dumping material to be separated by worm feed into a chamber or enclosure against an upward air current created by a blower or exhaust fan. The lighter materials are blown or drawn into an inverted cone-shaped or other type of collector.

The equipment employed for separating solid materials presents no particular sanitary problem.

Specific gravity for separation processes is employed in many operations. In the manufacture of lard, for example, water and a small quantity of salt are added to fatty pork tissue and heated under pressure for a suitable period of time. When cooking is completed, there is a layer of fat on top of the water; and solids consisting of bone and other tissue are at the bottom. Separation is accomplished by opening the valve at the proper level and carefully collecting the lard.

The separation of the sesame seed is accomplished by a similar flotation process. The seeds are dumped into a large tank to a point about one-fourth of the way up the tank. The tank is then filled with water, and the contents thoroughly agitated for a short period of time. A settling period is permitted during which the seeds and heavy matter settle to the bottom. Wormy seeds (in cases of slight infestation) and other light material, float and thus may be drawn off. Sufficient salt is then added to the mixture which is agitated to dissolve the salt. The specific gravity of the salt solution is greater than that of the sesame seeds so that, after a period, the seeds rise and may be drawn off from the top. The extraneous matter settles.

The sanitary problems in these processes of *floatation* and *submersion* are those previously described as hazards to the water supply system. The tanks and other equipment used should not discharge by direct connection to the sewer. The water inlets should be well above the rim of the tank or other device used. The tanks and equipment should be designed and constructed in accordance with the principles outlined for sanitary construction and should be maintained in a clean condition.

The separation of egg yolks and egg whites in *egg breaking* operations is achieved by the device illustrated in Fig. 27 (see page 200). This utensil is fitted to a knife edge held by two uprights over a shallow pan. The whole egg, when broken from the shell, is poured on the cup so that the yolk remains in the cup. The adhering white is cut off by dropping the hinged rim over the cup. Devices of this kind are difficult to clean at three points. They can be easily altered so that the pivot pin of the hinge is removable, the loop formed for the hinge does not have an open seam, and the loop at the back of the device into which the knife edge slips is readily accessible for cleaning to prevent the harboring of microorganisms.

The machine described on page 205 as a clarifier is a modification of the separator used to separate two immiscible *liquids* and liquids of varying densities or specific gravities, as in cream separation from fluid whole milk. The separator consists of an upright frame, a rotor bowl, and a cover which also acts as a receptacle. The separator bowl is operated at about 5800 revolutions per minute, achieved by a high-speed, motor-driven, vertical shaft upon which the rotor bowl rests. The power is transmitted to the rotor bowl through a notched shaft end. Most separator bowls consist of scores of bell-shaped fins or disks superimposed one on the other, but separated by a predetermined and adjustable gap. See Fig. 28, page 200. Each fin has two perforations in each segment, one near the center, the other near the periphery. The heavier liquid moves through the latter, the lighter fluid flows through the orifice

near the center. The cleaning and sanitary maintenance of this machine are the same as for the clarifier previously described.

4. Homogenization and Emulsification

(a) Homogenization

Many foods require homogenization, or the breaking down of their gross physical structure, in order to produce a relatively permanent mixture. This process is extensively employed in the milk industry for a certain type of fluid milk, and is essential in the manufacture of ice cream mix, cultured sour cream, and cultured buttermilk, as well as for the reconstitution of milk from powdered skim milk and butter oil. See Volume I, page 417. It also is indispensable in making clam broth. The canned frozen egg industry uses this process for the production of a whole egg product which will not separate when thawing.

This process is accomplished by homogenizers or colloid mills. The latter have already been described. See page 180.

The high-pressure *piston-type homogenizer* consists essentially of a cylinder head bored for three pistons and suitable valves which permit building up of high pressures so as to reduce oil globules or other similar structures to minute particles. This type of homogenizer, from the point of view of sanitary maintenance, at one time presented both a serious labor problem and a sanitary hazard. While no great difficulty existed in disassembling the valves, the removal of the head, because of its massive construction, made impractical frequent cleaning of the cylinders, valve ports, pistons, and stuffing boxes. There are many homogenizers still in service which are still a source of contamination and the cause of high bacteria counts. By alteration many of these homogenizers may be made easy to clean; for instance, by providing a device consisting of a cogged- or gear-toothed rack actuated by a pinion and crank to two parallel sides of the cylinder head, sufficient mechanical advantage may be gained to move the cylinder block. Once freed of its bolts by this process, the cylinder and pistons, and the valve ports and stuffing box are exposed for proper cleaning. Daily disassembly and cleaning and daily replacement of the piston packing with new or sterilized graphited asbestos packing will reduce contamination and high bacteria counts.

(b) Emulsification

The equipment generally employed for homogenization may be used for emulsification. The colloid mill and the homogenizer, but principally the vertical mixer (see page 176), are used for making such emulsions as mayonnaise and salad dressings.

5. Coating and Enrobing

Coating and enrobing (pages 45 and 577) are most widely used in candy making. Coating is usually accomplished by revolving large numbers of globular- or oval-shaped pieces of candy or other food pieces in an open metal pan (usually copper)

which may be steam-jacketed. The pan is mounted on a shaft which is set at an angle of approximately 45°. Small quantities of colored and flavored sirup, usually sugar sirup, are added at intervals to the revolving candy or other material. This process results in a thin, even, and smooth deposit or coating on the candy.

Enrobing, however, is achieved by passing the material to be treated through the enrobing material, usually chocolate liquor, by means of a chain or wire-mesh conveyor or by directing the material to a point beneath nozzles so that the enrobing substance may be poured on. The enrobed candy or other food center is then quickly chilled and removed from the conveyor belt. This process involves the use of equipment which is hard to clean. The chain or wire-mesh belt, as already described, contributes to a laborious cleaning problem, while the nozzles, piping, and pumps represent an additional sanitary maintenance difficulty.

6. Depositing

There are devices designed to deposit predetermined quantities of food material on traveling pans or belts, usually in a semisolid state, such as cookie dough or soft candy centers. Several principles of design are employed to accomplish this.

With the *piston* or *plunger type*, the food material is fed to a hopper installed above a cylinder. The food material usually is forced into the cylinder by a worm gear through an opening between the hopper and cylinder. This opening is controlled by a piston or plunger which is set in motion parallel to the axis of the cylinder. During the filling stroke, the plunger is pulled past the opening so that the worm may force food into the cylinder. During the discharge stroke, the piston passes the opening, shuts it off, and pushes a definite volume of food in the cylinder through the discharge opening. By the attachment of suitable dies, the discharged mass, if of proper consistency, may be shaped or formed.

In the *gear displacement type*, wide tooth gears rotate within the opening at the base of a hopper. The gears revolve outwardly, that is, the left gear turns counter-clockwise, the right one clockwise. Thus the interstices between the teeth become pockets, and are filled by gravity with the material to be deposited. When the gears mesh, the material is deposited by displacement. The volume of the depositor is regulated by the number of gear plates used on each shaft, and by the length of the stroke which controls the number of teeth emptied within the depositing period.

These devices must be constructed so that they can be disassembled easily and so that there are no dead ends, rough surfaces, and threads within the product zone. The piston type of depositor may function efficiently without the use of packing either at the piston head or shaft.

VI. ELECTROLYTIC ACTION OF METALS ON EQUIPMENT AND FOOD

Deterioration of equipment is frequently accelerated by failure of designers to consider the destructive effects of electrolytic action by the use of combinations of metals. The following summary may serve as a helpful suggestion in this connection.

1. Dissimilar metals, when used on a piece of equipment, such as a copper kettle with a steel or iron runoff valve, or when used for preparing a food product containing an acid or brine, set up an electrolytic action which soon causes corrosion of metal parts.
2. There have been numerous experiences recorded of flavor deterioration and pronounced color change, usually darkening, in food products containing, for example, traces of copper or iron which were processed in equipment made with parts of different metals. The proper selection of metal for use with a food product containing trace salts (metallic compounds) is essential.
3. Food equipment parts made of metal may cause equipment difficulties like rapid depreciation, high maintenance costs, and poor food quality if the metals used are impure or are alloys of metals which can produce a potential difference in contact with certain foods.
4. Faulty grounding or insulation has been reported as the cause of deterioration of metal parts of equipment because of electrical currents leaking through the equipment.

VII. MAINTENANCE OF PRODUCTION RATE

In the discussion of the sanitary design and construction of food machines and equipment, the suggestions made were carefully considered from the standpoint of maintaining the production rate. Experience has shown that the construction of sanitary drive shafts, sanitary seals of the rotary type, and other sanitary equipment parts is adequate for the proper transmission of power or for the other functions for which they are intended, and will promote not only quality control through sanitation but good plant practices through easing the cleanup burden.

Chapter VI

WASHING, DETERGENCY, SANITATION, AND PLANT HOUSEKEEPING

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Close attention to sanitation and plant housekeeping is essential for the highest achievement in the operation of any business concerned with food and food products. A sound working knowledge and a diligent application of certain facts concerning washing and detergency by executive and factory employees are necessary if high standards of sanitation and plant housekeeping are to be maintained. Esthetic tastes and legal regulations require a certain degree of sanitation. Furthermore, in the long run a high standard of sanitation and plant housekeeping pays dividends through improved quality and lower spoilage of products, better product acceptance, less loss of time through accidents and plant breakdowns, and an improved employee morale.

It will be the aim in this discussion to present certain general principles and to call attention to various kinds of materials and methods which are available for use in cleaning and plant housekeeping, rather than to attempt to present detailed directions for handling the multitudinous specific problems which exist in various kinds of food processing plants. First, we shall consider washing and detergency, and then give attention to the broader subjects of sanitation and plant housekeeping.

I. WASHING AND DETERGENCY

Old as the problems of cleaning and washing are, and in spite of the large amount of research which has been done on these problems, there are many phases still incompletely understood insofar as the details of the chemistry and physics involved are concerned.

1. Principles of Washing

Washing, however, may be considered as involving three steps:

1. Separation of the soil from the object to be cleaned.
2. Carrying the soil away and disposing of it suitably.
3. Leaving the surface being cleaned in the desired condition.

Throughout the literature on washing and detergency one reads much of such terms as neutralization, saponification, surface tension, interfacial tension, wetting power, emulsification, deflocculation, alkalinity, ρH , buffering capacity, rinsibility, colloidal properties, etc. Such factors as neutralization, ρH , alkalinity, buffering capacity, surface tension, interfacial tension, wetting ability, and mechanical action are all involved in the actual separation of the soil from the surface being cleaned. Emulsification and deflocculation (which in turn involve such factors as surface and interfacial tension, concentrations of surface-active agents, and ρH) are involved in carrying away and disposing of the soil which has been loosened from the surface. The main object to be achieved in this second step is to prevent the soil from being redeposited upon the surface and to dispose of it in a manner which will not create a nuisance. The condition in which the surface of the object is left after the cleaning operation, is dependent upon the action of the cleaning solution upon the surface, the rinsability of the wash solution, hardness of water, temperature of final rinse process, germicidal properties of the wash and rinse solutions, and method of drying the object.

2. Theories of Cleaning

There are various theories concerning the mechanism of cleaning. Each appears to fit certain observations and facts concerning certain kinds of cleaning operations, but no single theory so far advanced is adequate to explain all observations. It therefore seems probable that cleaning processes are rather complicated phenomena with various types of mechanisms playing a part and that the relative importance of each depends upon the particular type of cleaning problem involved and the many variable conditions which may enter into the situation.

Those interested in the details of these various theories may refer to the literature for such information. However, it may be worth while to consider one or two types of explanation of what happens in the cleaning process.

It is usually assumed that the soil consists in part of oily substances which contain some free fatty acids. Soap formed by the action of this free fatty acid with the alkaline materials in the wash solution, together with other surface-active substances which may be present in the wash solution, tends to lower the surface and interfacial tensions. This, together with the accompanying mechanical action, tends to loosen the soil from the surface and to emulsify or deflocculate it by the formation of a protective film around each tiny speck of soil. The protective film is pictured as consisting of surface-active molecules, so oriented that the water-soluble (hydrophilic) groups face outward into the wash solution and the oil-soluble (hydrophobic) portions of the molecules face inward toward the speck of soil, being dissolved in the oily portion of the soil. These protective films tend to keep the particles of soil which have just been removed from the surface from collecting or coalescing into aggregates large enough to separate out from the washing solution. They also tend to prevent the redeposition of this soil upon the surface which has just been cleaned.

Electric phenomena are considered to play a part in dispersion and deflocculation and also in adsorption of the soil by colloids when colloidal detergent materials are used.

There are many different factors which have an influence on the cleaning operation. Some of the more important to be considered in connection with any given cleaning problem are listed in Table 16.

TABLE 16
FACTORS AFFECTING CLEANING OPERATIONS

Surface to be cleaned.....	Chemical and physical properties, size, shape, location
Soil to be removed.....	Kind, amount, time on surface, action on surface
Purpose of cleaning.....	
Water supply.....	Abundance, heating facilities, hardness, iron, other impurities
Cleaning agent.....	Specially adapted to job or just general purpose type, effect on object being cleaned, effect on user, effect on brushes or other cleaning equipment
Temperature.....	Effect on soil, effect on object being washed, best for washing solution, best for rinse, etc.
Cleaning method and equipment.....	Hand, machine, simple, complex, brushing, spraying, dipping, soaking

3. Methods of Cleaning

There are a great many different methods of cleaning and types of phenomena involved in cleaning operations. One way of classifying these is shown in Table 17. In most cases, several of the phenomena listed in Table 17 are involved simultaneously or successively in each cleaning job.

TABLE 17
BASIC PHENOMENA OF DETERGENCY

Physical	Abrasive, brushing, burnishing, wiping, etc. Flushing, hosing, spraying, etc. Agitation, stirring, vibration, tumbling, etc. Screening, filtering, selective adsorption, etc. Gravitational, settling, flotation, centrifuging, etc. Moving materials, conveying, turning, pumping, etc. Wetting, surface and interfacial phenomena
Chemical	Neutralization, oxidation, reduction, exchange reaction, adsorption, enzyme action, solution, emulsification, deflocculation, precipitation, etc.
Electrical	Electrolytic, electrostatic, magnetic, adsorption and colloidal phenomena
Thermal	Heating, cooling, expansion, contraction, vaporization, condensation, drying, increasing chemical action, etc.

TABLE 18

CHEMICALS USED FOR WASHING, DETERGENCY, AND PLANT SANITATION

CLASSES	
<i>Classes:</i> solvents, surface-active agents, alkalies, acids, salts, abrasives, reducing agents, oxidizing agents, inhibitors, enzymes, germicides, adsorbents	
1. SOLVENTS	
Water	By far the most important. Water from most supplies contains <i>hardness</i> and other dissolved impurities, some or all of which may need to be removed before use if best detergent results are to be obtained.
Other solvents	Organic solvents such as various hydrocarbons and chlorinated hydrocarbons are of limited usefulness in the food field but are of major importance in some other industrial cleaning fields. In using organic solvents, one must consider toxicity, inflammability, recovery and re-use, and other such factors. Select on basis of "like dissolves like."
2. SURFACE-ACTIVE AGENTS	
Ordinary soaps	Salts of mixed, straight-chain fatty acids of length C ₈ to C ₁₈ . Properties vary with such factors as chain length, amount of unsaturation, proportions of different fatty acids present, and alkalies used in making the soap. In general, the lower-titer soaps (those made from short-chain and/or unsaturated fatty acids) are more soluble and give optimum detergent results at a lower temperature than is the case for the higher-titer soaps (those made from longer chain and saturated fatty acids). Sodium soaps are the most common, but potassium and ammonium soaps are also used for washing purposes. The pH of solutions of ordinary soaps is of the order of 10. Soaps possess excellent detergent and wetting properties but are useful in such capacities only in alkaline solutions of pH about equal to or greater than that of the pure soap. The hardness in water precipitates soaps and interferes with their action. Unless the water is otherwise softened, more than sufficient soap to precipitate all of the hardness must be added before the soap can begin to exert its detergent action. In softened water a soap concentration of the order of 0.1% is sufficient in most cases. The cleaning ability of soap solutions can be considerably enhanced by the addition of suitably selected alkaline salts. Addition of wrong materials can decrease the cleaning action.
New "soapless" soaps, synthetic compounds, detergent and wetting agents	These new chemicals represent attempts to make compounds which possess the good detergent and wetting properties of ordinary soaps without the disadvantages of being adversely affected by acids, salts, and water hardness. The hundreds of different chemicals which have been suggested for this purpose may be considered as belonging to one of three general types, anionic, cationic, or nonionic. Solutions of most of these newer materials have a pH near that of neutrality (usually between 5 and 8). The anionic materials generally do best cleaning when used in acid solutions, and the cationic when used in alkaline solutions. The nonionic are less influenced by the pH of the solution. Some of these materials possess marked bacteriostatic and germicidal properties. It is difficult, expensive, and in some cases impossible, to prepare some of these new chemicals by themselves in the form of dry solids. The rate of dissolving of the pure chemicals is sometimes very slow. Therefore, many of these new materials which are available commercially are sold in the form of aqueous solutions of various concentrations. In other cases they are prepared in a dry form by mixture with some dry but easily water-soluble material, such as sodium sulfate. Since the wetting and detergent effectiveness of many of these newer surface-active agents is greater in neutral salt solutions than in pure water, the sodium sulfate serves as more than a mere carrier or inert filler. A few examples of these newer types of detergent materials which are in commercial production are:

	Class	Chemical type	Trade names
New "soapless" soaps, synthetic compounds, detergent and wetting agents (<i>Contd.</i>)	Anionic	Alkyl sulfates Alkyl aryl sulfates Dialkyl esters of sodium sulfo-succinic acid	Duponols, Cardinols, Modinols, Orvus Aerosol AS, Alkanols, Nacconols, Santomere Aerosol AY, IB, MA, OS, OT
	Cationic	Trialkyl benzyl ammonium halide Alkyl pyridinium halides Others	Zephiran, Triton K-12, Triton K-60, Retarder LA Ceprym chloride, Emulsol-660-B Damol, Hydrocide, Emulsol-605, Emulsol-606, Negamine, Stearonyl, Beta Sol
	Nonionic	Polyethers	Intrals 222, 231, 233, Triton NE

3. ALKALIES

Sodium hydroxide	Sodium hydroxide (caustic soda, lye) is the most important alkali from a detergent standpoint. It is used alone in concentrations of the order of 2 to 3% very extensively in the milk and carbonated beverage industries for machine washing of bottles. It serves as both a detergent and a germicide in this use. Sometimes other detergent materials are used with it to modify results. Other applications of caustic soda itself as a detergent in the food field are few and small in comparison to its use in bottle washing. However, very large amounts of it enter the detergent field indirectly through its use for the manufacture of soaps and other alkaline detergent materials. Caustic soda must be handled and used with extreme care to prevent the user from receiving bad caustic burns. Some of the alkaline salts mentioned below can take care of most of the washing jobs for which caustic soda is useful. These salts are less dangerous to handle and often do a better job than can caustic soda alone.
Potassium hydroxide	Potassium hydroxide (caustic potash) is practically never used directly as a detergent because it is much more expensive than caustic soda. It is used to make potassium soaps. Potassium soaps are more expensive than corresponding sodium soaps and therefore their use is limited. They are more soluble than the corresponding sodium soaps and are used for special purposes, where increased solubility is desired, for instance, in liquid hand soaps for use in liquid soap dispensers such as are installed in washrooms.
Ammonium hydroxide	Ammonium hydroxide can be used where a mild alkaline cleaning material is desired. However, it is seldom used. Its main advantage over other alkaline materials is that it is completely vaporizable at ordinary temperatures and therefore leaves no residue. It is also seldom used for making soaps, some of its soaps being unstable. It enters indirectly into the detergent field to a limited extent through its use as a starting material in the making of certain types of amines which are of growing detergent importance.
Amines and organic bases	In the last few years, there has been some work in the direction of producing various amines and certain organic bases which are finding some use as detergents. For instance, such compounds as triethanolamine can react with fatty acids to give triethanolammonium soaps, which have useful detergent properties. Some of the newer surface-active agents of promise are derived from amines.

4. ACIDS

Hydrochloric, sulfuric, and nitric acids	These are strong acids, useful for some special cleaning purposes but hazardous to handle. Their direct uses for detergent purposes are limited. Indirectly, they contribute to detergency in that they are employed in the manufacture of other cleaning materials.
Organic acids	Recently, certain organic acids such as lactic, gluconic, and levulinic acids have been suggested for certain detergent purposes. The direct use of organic acids as detergents is as yet very limited in comparison to their indirect use in the manufacture of soaps and other surface-active agents.

TABLE 18 (*Continued*)
CHEMICALS USED FOR WASHING, DETERGENCY, AND PLANT SANITATION

5. SALTS	
Kinds	There are many kinds of salts used for detergent purposes. Most cleaning is done with the aid of some salt. Ordinary soap is a salt. Salts may be classified in various ways, such as neutral, buffer, acid, and alkaline.
Neutral	Neutral salts like sodium chloride and sodium sulfate have detergent uses in connection with some of the newer types of synthetic detergents.
Buffer	Salts of strong acids and weak bases, or of weak acids and strong bases, are useful as buffer salts, or buffering agents which tend to protect the detergent solution from large changes in ρH due to changes in concentration or the addition of alkaline or acidic substances into the wash solutions.
Acid	Acid salts, such as sodium acid sulfate, are useful when an acid cleaning solution of moderate strength is desired. The acid salt is usually more convenient to ship and handle than the corresponding acid.
Alkaline	The greatest proportion of all cleaning work is done with some type of alkaline salt. In this class fall all ordinary soaps and such widely used detergent materials as sodium carbonate, the silicates, and the phosphates. Soaps have already been discussed. The other common alkaline salts will be presented in the next section of this table. Many other materials, listed elsewhere because of some special property, are also salts of one kind or another.
6. ALKALINE SALTS	
Borates	Borax (sodium tetraborate), $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$, produces only mildly alkaline solutions. It was formerly widely used for water softening and detergent purposes, but in recent years has been increasingly displaced by other alkaline salts which are better suited for most detergent uses. Sodium perborate, $\text{NaBO}_3 \cdot 4\text{H}_2\text{O}$, is a mild oxidizing agent.
Carbonates	Sodium carbonate is one of the most important alkaline detergent salts, not only for its own detergent uses, which are many, but because it is used in the manufacture of other detergent materials. It is used alone for general detergent purposes, and in combination with other detergent materials, and sells for a very low price per pound. The anhydrous form, Na_2CO_3 , known to the trade as <i>soda ash</i> , is the most commonly used form. Soda ash is available in three different states of granulation, known as <i>dense</i> , <i>light</i> , and <i>extra light</i> . The light ash is the form most widely used. Two hydrated forms $\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$ and $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$ are available commercially, but are not as economical to use as soda ash. The decahydrate, known as <i>sal soda</i> or <i>washing soda</i> , has for years been used by housewives for water softening and washing purposes. Sodium bicarbonate, NaHCO_3 , commonly known as <i>baking soda</i> , and <i>bicarbonate of soda</i> , provides very mild alkaline solutions of limited detergent value. The bicarbonate is sometimes used with other alkaline materials to reduce the alkalinity of their solutions. Sodium sesquicarbonate, $\text{NaHCO}_3 \cdot \text{Na}_2\text{CO}_3 \cdot 2\text{H}_2\text{O}$, contains equimolecular quantities of sodium carbonate and bicarbonate. It is used to a small extent where a mildly alkaline agent is desired. Modified sodas are available commercially as several combinations of soda ash and caustic soda, sometimes called <i>causticized ash</i> . These provide a means of obtaining highly alkaline solutions without the handling hazards involved in using caustic soda itself. In case carbonate solutions of lower alkalinity than supplied by soda ash are required, soda ash-bicarbonate mixtures of various proportions can be obtained.

Phosphates:
ortho-

Trisodium orthophosphate, with twelve molecules of water of crystallization $\text{Na}_3\text{PO}_4 \cdot 12\text{H}_2\text{O}$, known to the trade as TSP, is one of the most important alkaline detergent salts. It is widely used alone for a great variety of detergent purposes. It is also a component of many different detergent combinations. It is superior to sodium carbonate for many uses. It is widely used as a water softener in washing operations and is claimed to give the solutions good emulsification properties. TSP is available in such forms as crystals, flakes, and globules, but the crystalline form is by far the most common and for most purposes is the best. Anhydrous and monohydrate trisodium phosphate are also available but are seldom used alone for washing purposes. Disodium monohydrogen orthophosphate provides a very mildly alkaline solution, but is not important as a detergent material in comparison with borax and sodium bicarbonate, which also provide mildly alkaline solutions.

pyro-

Tetrasodium pyrophosphate is available in both the anhydrous form and as a decahydrate, $\text{Na}_4\text{P}_2\text{O}_7 \cdot 10\text{H}_2\text{O}$, and is sometimes referred to as TSPP or as *pyro*. Pyrophosphate is less alkaline than TSP and possesses excellent water softening and dispersive properties. It is seldom used alone as a detergent but in the last few years has come into wide use as a *soap-builder* and as a component of various detergent combinations. The anhydrous form is much cheaper to use than the hydrated which is of little importance in industrial cleaning.

poly-

Sodium salts of phosphoric acids which are more highly dehydrated than pyrophosphoric acid are sometimes referred to as polyphosphates. Those of commercial importance are produced as phosphate glasses and sold in the form of broken plates, pellets, flakes, or granulated powder. Solutions of the most highly dehydrated polyphosphate, sodium hexametaphosphate, $\text{Na}_6\text{P}_6\text{O}_{15}$ in pure form, are slightly acid so that, strictly speaking, this is not an alkaline salt. However, the commercial product is not pure and in most detergent uses some alkaline salt such as soda ash, TSP, or pyro is present to make the solution alkaline. The product sold commercially as sodium tetraphosphate, $\text{Na}_4\text{P}_4\text{O}_{13}$, is alkaline in solution. These phosphates possess exceptionally good water softening properties and differ from orthophosphates and the carbonates in their softening action in that they can soften water without the formation of any precipitate. They are seldom used alone but rather in solutions containing other detergent materials. It is probable, however, that they possess some values in detergent solutions in addition to water softening. Sodium tripolyphosphate, $\text{Na}_5\text{P}_3\text{O}_{10}$, is another polyphosphate available commercially which is said to possess similar water softening properties.

Silicates:

ortho-

There are a large number of sodium silicates on the market, and several of them are important as detergent materials. A few are used alone for some cleaning purposes. These and others are used in combination with soap or other chemicals as washing agents. These silicates range in alkalinity from the very highly alkaline compound, sodium orthosilicate, down to certain water glasses which are only very slightly alkaline. The detergent value of the silicates depends not alone on their alkalinity but to a very large extent upon other factors, such as their colloidal and dispersive properties, and their ability to protect surfaces being cleaned from the damaging effects of highly alkaline solutions.

sesqui-

Sodium orthosilicate, Na_4SiO_4 , is the most alkaline silicate commercially available. It approaches caustic soda in its alkaline strength. It is not used for general cleaning purposes, but is useful for special jobs which require very caustic solutions. This product is very hygroscopic and should be stored in a tightly closed container to prevent it from deliquescing. Sodium sesquisilicate, $\text{Na}_4\text{SiO}_4 \cdot \text{Na}_2\text{SiO}_3 \cdot 11\text{H}_2\text{O}$, is less alkaline than the orthosilicate, but is too strong for general detergent use and therefore serves only when very strongly alkaline solutions are required. This product too is hygroscopic.

VI. SANITATION AND PLANT HOUSEKEEPING

TABLE 18 (*Continued*)

CHEMICALS USED FOR WASHING, DETERGENCY, AND PLANT SANITATION

Silicates: (*Contd.*)
meta-

Liquid silicates, powdered silicates, and water glass

Sodium metasilicate, available in the anhydrous form, Na_2SiO_3 , and as the pentahydrate, $\text{Na}_2\text{SiO}_3 \cdot 5\text{H}_2\text{O}$, is much weaker than either the ortho- or the sesquisilicate, but is considerably stronger than TSP or soda ash. Several other hydrates can be prepared, but are not so commonly available as the above forms. Sodium metasilicate represents a happy medium between the highly caustic product and the more siliceous products, combining the good detergent action of an alkali with the special colloidal and protective properties attributable to the silicate anion. It is very widely used alone as a detergent material and is an important component of many detergent combinations. It is slightly hygroscopic but not sufficiently so to give much difficulty in handling except under very humid conditions. The product is too strong to be recommended for uses where the unprotected hands of the user are exposed to its solution.

Silicates are frequently described in terms of the proportion of alkali to silica present in them. This composition is expressed in the form of the molecular ratio of Na_2O to SiO_2 . The $\text{Na}_2\text{O}:\text{SiO}_2$ ratio of sodium orthosilicate is 2:1, of sodium sesquisilicate 1.5:1, and of sodium metasilicate 1:1. All of the above substances are readily soluble in water. There are available a number of dry, powdered sodium silicate products which have a $\text{Na}_2\text{O}:\text{SiO}_2$ ratio of less than 1:1, although it is claimed that no definite chemical compounds, in the strict meaning of the term, exist with ratios of less than 1:1. As the ratio of Na_2O to SiO_2 decreases, the difficulty of getting the dry silicates into solution increases. The lower-ratio silicates are therefore usually supplied in the form of concentrated solutions. Ordinary water glass has a $\text{Na}_2\text{O}:\text{SiO}_2$ ratio of less than 1:3. These low-ratio silicates are seldom used alone for detergent purposes, but have long been used as soap builders. They are not as important for cleaning in food industries as the more alkaline silicates, especially metasilicate.

7. ABRASIVES

Pumice stone, powdered silica, emery, steel wool, etc.

Abrasives are seldom used alone. When properly selected to give strong abrasive action with as little damage as possible to the surface being cleaned and in conjunction with other cleaning agents, they are very useful, especially for the removal of burned-on foodstuffs and other soils which adhere very tenaciously to the surface to be cleaned.

8. REDUCING AGENTS

Sodium bisulfite, sodium sulfite, etc.

Sodium bisulfite, sodium sulfite, and other reducing agents are useful in certain specialized cleaning problems, especially those involving the removal of discolorations and stains.

9. OXIDIZING AGENTS

Hypochlorites, peroxides, perborates, oxalic acid, etc.

Oxidizing agents, as well as reducing agents, are useful in certain specialized cleaning problems involving the removal of discolorations and stains.

10. CORROSION INHIBITORS

For alkaline solutions

Many surfaces are damaged by strongly alkaline or strongly acid solutions unless suitable inhibitors are present to protect the surface or modify the action of the solution. Silicates, when present in proper amounts, will protect aluminum from the attack of alkaline cleaning solutions, and reduce the attack of alkalies on tin and other surfaces. Chromates, barium salts, sodium silicofluoride, and some other salts are reported to be helpful in protecting tin and other metal surfaces. In the case of tin, at least part of the damage is done by oxygen dissolved in the alkaline wash solution. Removal of the dissolved oxygen by means of a reducing agent such as sodium sulfite will prevent much of the attack on tin.

For acid solutions	A number of organic substances, such as certain amines, have the ability to reduce the attack of acid solutions on metal surfaces.
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11. ENZYMES

Proteolytic, starch solubilizing, fat splitting	Enzymes have been employed in only a very limited way for cleaning purposes but deserve more attention. Care must be used to select conditions of pH and temperature suitable for the particular enzyme used. Enzymes to be used must, of course, be selected on the basis of the type of soil to be removed. For instance, diastase, a starch-solubilizing enzyme, is useful in the removal of a starch soil but would not be useful in the removal of a fat soil.
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12. GERMICIDES

Caustic soda, available chlorine compounds	Caustic soda and various hypochlorites are most common. Certain phenolic derivatives, N -chloro compounds, and new surface-active agents are finding use in this field. Germicides and germicidal methods are discussed elsewhere in this chapter.
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13. ADSORBENTS

Sawdust, celite, bentonite, etc.	Sawdust, celite, bentonite, and other similar materials possess adsorptive properties which are of value in certain cleaning and plant housekeeping operations. Usually such materials are used in conjunction with other cleaning agents for the purpose of adsorbing and holding on to certain types of soil so that they can more easily be carried away from the surface being cleaned.
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(a) *Chemicals*

There are hundreds of different types of cleaning combinations used; and a great many different individual chemicals possess cleaning properties. It will not be possible here to consider even a small fraction of these various combinations or even to discuss fully the much smaller number of chemical substances which are used in these cleaning compositions. An attempt will be made, however, to list the more important of the chemical substances and in some cases to give information relating to their detergent properties. See Table 18 for examples of these types of materials. A few chemicals will be discussed individually later in the chapter.

So much is said about alkali strength and buffering capacity in detergent literature that there is sometimes a danger of overlooking other factors which have a bearing on the type of results obtained. However, it is useful to have some conception of the comparative alkalinity and neutralizing capacity of the alkalies and alkaline salts used in detergency. A rough idea of the relative strength and amount of alkalinity which solutions of some of these substances provide may be obtained from a study of the data in Table 19.

In Tables 18 and 19 are listed most of the important chemicals available for cleaning purposes, together with certain information concerning their properties and usefulness. It should be understood, however, that in many cleaning operations the most efficient and most effective cleaning materials will be found to consist of more than a single chemical, for certain combinations of chemicals will in general provide a more suitable cleaning material for a given purpose than will any single chemical substance.

An understanding of the properties and usefulness of individual chemicals, however, is helpful in the selection of combinations of these chemicals for use in specific cases.

In the use of chemicals for cleaning purposes more attention than is customarily the practice should be paid to the concentration used. Too often, the worker proceeds under the assumption that if a little does some good, more will do proportionally greater good. This may be true for each chemical within rather narrow limits, but certainly is not universally applicable over the extreme range of concentrations and

TABLE 19
COMPARISON OF ALKALINITY OF SOME DETERGENT SUBSTANCES

Chemicals (commercial grade)	pH (approx. for soln. of the weight per cent indicated)		Amount of alkalinity (approx. for a 0.5% solution) ^a	
	0.1%	0.5%	Phenolphthalein	Methyl orange
Caustic soda	11.9	12.7	122	122
Sodium orthosilicate	11.8	12.6	100	106
Sodium sesquisilicate	11.6	12.3	58	60
Sodium metasilicate	11.3	12.0	45	48
Trisodium orthophosphate	11.5	11.8	18	35
Soda ash	10.7	11.3	56	95
Sodium sesquicarbonate	9.6	9.7	28	68
Sodium pyrophosphate	9.0	9.5	12	38
Borax	8.5	8.7	20	28
Sodium bicarbonate	8.0	8.2	3	61

^a Expressed as the number of milliequivalents of acid required to bring 1 l. of soln. to the phenolphthalein and methyl-orange end points.

TABLE 20
MECHANICAL AIDS TO CLEANING

Containers, holders.....	Vats, tanks, tubs, buckets, etc. Racks, baskets, brackets, hooks, etc.
Flushing equipment.....	Pumps, hoses, spray nozzles, compressors, etc.
Abrasive aids.....	Scrapers, brushes, squeegees, sponges, rags, metal wool, abrasive compounds, etc.
Screens and filters.....	
Machines.....	Agitators, motor-driven stirrers, -pumps, -sprayers, -brushes, tumblers, centrifuges, special washing machines
Heaters.....	For local water heating, drying, etc.
Moving aids.....	Hoists, elevators, conveyors, moving belts, trucks, boxes, baskets, racks, etc.
Drying aids.....	Centrifuges, squeegees, towels, fans, vacuum equipment, heating equipment, etc.

uses to which the ordinary user attempts to apply it. Generally, there is a concentration for each chemical which is the optimum and economical concentration to use. This will vary for each chemical and for each application depending upon the particular property of the chemical which plays the dominant role in the particular cleaning job and method being used. Sometimes a high concentration will actually give poorer results than will a lower concentration. Sometimes no value at all is received until a certain minimum concentration is reached. In other cases, even very small amounts of chemical do good and continue to give proportionally better results over a long range

of increased concentrations. The optimum concentration to use from the standpoint of soil removal may not always be the most economical concentration to use from the financial standpoint. Not only the cost per pound of the chemical itself, but also the other cleaning costs, such as for hot water, labor, etc., and the variation of these costs with the detergent concentration have a bearing upon the final cleaning costs. Most users err on the side of using more detergent than is required or is economical. Intelligent use of experience with each particular application is necessary to determine the proper concentration to be used.

(b) *Mechanical Aids*

Mechanical aids as well as chemicals are required for efficient cleaning operations. Various mechanical aids for cleaning are classified in Table 20.

4. Degrees of Cleanliness

Cleaning processes cost money. It is only natural, then, to attempt to determine how clean an object needs to be and when it has reached that degree of cleanliness, in order to avoid wasting material, time, and labor by continuing the cleaning process longer than is needed to give the required cleanliness. There are no absolute and well-established methods of measuring cleanliness except in a few very specialized fields, nor are there universal standards of cleanliness. Arbitrary standards and methods for judging results are usually devised for each type of operation; and these may vary a great deal from plant to plant. In general, however, three degrees of cleanliness may be recognized:

1. Physically clean, *i. e.*, clean to sight and feel. This is the degree least difficult to obtain and most widely desired.

2. Chemically clean, *i. e.*, free of traces of undesirable chemicals (too small to be seen or felt but yet sufficient to influence the quality of the product). Even very small traces of some chemicals can affect the taste, odor, color, or keeping quality of food products.

3. Bacteriologically clean, *i. e.*, free of undesired microorganisms.

All three degrees of cleanliness are important in the food industry. Frequently all three are required to obtain a desired result. In other instances, perhaps only two of these are essential. In practically all cases, however, the first degree, that is, clean to sight and feel, is necessary; and without first having this it is difficult, if not impossible, to obtain the desired degree of chemical or bacteriological cleanliness.

There is need for more scientific study and research in connection with the problem of measuring detergency and establishing quantitative standards for cleaning. There are, however, certain general methods which can be applied to the problem of judging the degree of cleanliness achieved in practice. The degree of physical cleanliness obtained is usually estimated by the simple expedient of a close visual inspection or by feeling the surfaces with the finger tips. Chemical cleanliness may be judged in a practical way by noting whether or not the quality of the product has suffered an adverse change in color, odor, taste, or keeping quality as a result of contamination

from the equipment in question. Bacteriological cleanliness can be tested by using bacteriological methods to determine the number and kind of microorganisms left on the object being cleaned or by observing whether the food products are coming through the process with the desired low bacteriological count.

5. Types of Detergents

(a) Water and Water Softeners

The most common and most used chemical for cleaning purposes is ordinary water. As common and well known as water is, it will nevertheless be worth while to consider certain facts concerning it in relation to detergency. Most available water supplies furnish water which contains considerable amounts of calcium and magnesium salts (commonly referred to as hardness) and other dissolved substances which may be detrimental to the use of water for cleaning purposes. See page 804. Just how detrimental these substances will prove to be in any given case will depend upon the particular cleaning job to be done, the type of cleaning materials available, and the kind and amount of impurities present in the water. It is common knowledge that water hardness causes difficulties in cleaning, especially when ordinary soap is used as the detergent, but too few realize the savings which frequently can be made and the improvement in the results which can be obtained by installing suitable water-softening systems or by selecting detergent materials which are not adversely affected by the water hardness. Too often, the initial cost of installing suitable water-softening equipment or the higher cost per pound of some chemicals is permitted to overshadow the somewhat hidden and less easily calculated savings which can be made by using soft water or cleaning materials which are especially adapted for hard water use.

Such water-softening processes as the soda-lime method and the zeolite water softener system, and such water-softening detergents as soap, sodium carbonate, and trisodium phosphate, are discussed on pages 811 *et seq.* Attention should be directed, however, to certain newer materials which are of assistance in combating water hardness in detergent operations.

There have recently become available on the market water-treating systems which are capable of removing not only the water hardness, but all of the dissolved materials from the water, giving water of the same order of chemical purity as distilled water. These systems are based on the flow of the water through beds of suitably selected resins, the first bed serving to remove the cations from the solution and the second bed serving to remove the anions.

(b) Special Phosphates

A second type of chemical which has become available in recent years for water-treating purposes is exemplified by such commercial products as Calgon and Quadrafos, which are represented as being, respectively, sodium hexametaphosphate, $\text{Na}_6\text{P}_6\text{O}_{18}$, and sodium tetraphosphate, $\text{Na}_4\text{P}_4\text{O}_{13}$. These phosphates have the ability to sequester the calcium and magnesium ions in such a manner that the ions are not free to react with soap and other detergent materials, and, furthermore, to accomplish this without

the formation of precipitates such as are obtained when water is softened by use of soap, sodium carbonate, or trisodium phosphate. It is a well-established fact that in many washing processes where water, even of low hardness, is used with ordinary cleaning materials, a film or residue is left on the surface. This film can harbor and protect microorganisms and in many cases builds up to such a thickness as to be visible, and undesirable from that standpoint. Such films are apparently caused by the reaction of the water hardness with the detergent material to form precipitates which tend to adhere to the surface. Such films also tend to hold some of the soil onto the surface so that the washing and rinsing process does not effect complete soil removal.

Experiments with these phosphates have shown that, when properly used, they can soften water without the formation of undesirable hard water films. Furthermore, if sufficiently high concentrations are used, their solutions are capable of redissolving films which have already been formed as a result of previous washings under unfavorable conditions. They have the ability to prevent crystallization and crystal growth. They possess good dispersive properties also. Calgon and Quadrafos as commercially produced are in the form of a "glass" formed by the rapid quenching of the melted phosphate. This formation of a glass upon quenching is characteristic of phosphate melts which contain ratios of $\text{Na}_2\text{O}/\text{P}_2\text{O}_5$ in the region between 2 : 1 to 1 : 1. Presumably, any number of such phosphate glasses may be formed depending upon the exact ratio of Na_2O to P_2O_5 present in the melted phosphate. Such phosphate glasses are sometimes referred to as polyphosphates.

If the $\text{Na}_2\text{O}/\text{P}_2\text{O}_5$ is 2:1, one may obtain a crystalline compound known as tetrasodium pyrophosphate. This product, frequently referred to commercially as pyrophosphate, or simply as "pyro," is an excellent detergent material. It is a very good dispersive agent. If the water hardness is not too great, it can prevent the formation of hard water precipitates. It is not so effective in this respect, however, as the polyphosphates mentioned above. Pyrophosphate and the polyphosphates are sometimes referred to as molecularly dehydrated phosphates, since they are salts of phosphoric acids containing less water in proportion to P_2O_5 than orthophosphoric acid contains. These molecularly dehydrated phosphates are finding increasing use as detergent materials.

(c) Synthetic Detergents

A third type of chemical to be considered for use in combating water hardness is that group of compounds commonly referred to as soapless soaps, wetting agents, and synthetic detergents. The calcium and magnesium salts of these newer types of surface-active materials are soluble, and not detrimental to the detergent action of these materials. In fact, in some cases, these newer types of detergents seem to give better washing results in the presence of water hardness than in the absence of it. These newer detergents are already finding considerable application in the detergent field and deserve very serious consideration by those responsible for cleaning and sanitation in food plants. In testing out and attempting to use these newer detergent materials, it should be realized that the conditions which will enable them to give best

results may be entirely different from the conditions traditionally considered as necessary for good detergent action. For example, in the past it has been more or less accepted that washing should be done in an alkaline medium. This condition was not only best but absolutely essential for the successful use of the cleaning materials available in the past, such as ordinary soaps and alkaline salts. While many of these newer detergent materials will give good results when used in alkaline medium, most of those commercially available, and especially those of the anionic type, will give better results when used in acid solutions.

Recent laboratory and plant experiments by several workers in the food industry indicate that some of these newer surface-active agents show promise of being very useful substances, not only for their cleaning ability, but also because of their action on microorganisms. These materials deserve serious consideration from that standpoint.

(d) Acid Detergents

Attention should be called to another type of chemical which has been receiving considerable attention and publicity in the milk industry. Reference is made to certain organic acids which have been used in combination with certain other materials to give what has been referred to as acid cleaners or acid detergents. The particular application to which these so-called acid detergents have been applied is that of milk- and cream-can washing. It has been the common practice to wash such cans in special washing machines which use an alkaline cleaning material. Sometimes the cans develop foul odors which are claimed to be responsible in some instances for off-flavor and poor quality in milk products. It is claimed that when the milk cans are washed in the alkaline cleaning material a thin film of protein-containing substance is left on the surface of the can and that the *pH* of the surface, being slightly alkaline, favors the growth of putrefying microorganisms which react with the protein-containing film in such a manner as to cause the foul odors. The use of the acid detergent to overcome this problem is based on the idea that, if the washing solution is acid, the protein-containing film will not be deposited upon the surface of the cans, and furthermore that the *pH* of the surface will be on the acid side and unfavorable for the development of the putrefying microorganisms. Inorganic and organic acids commonly available commercially in the past have too corrosive an action on the metal surface to be suitable for this use. Experiments with various organic acids have indicated that certain ones, as for instance gluconic acid, have very much less corrosive action than such commonly available acids as acetic and the ordinary inorganic acids. Further experiments in this direction have led to the use of acid detergents consisting of a combination of substances like gluconic acid, levulinic acid, and calcium propionate, with certain inhibiting substances to further cut down corrosive action and certain of the newer types of surface-active materials, commonly referred to as wetting agents. The levulinic acid, the propionate, and the wetting agents serve to inhibit the growth of microorganisms; and the wetting agents presumably furnish most of the detergent action. It is claimed that this type of material works best when employed in machines especially built for its use. There is some indication, too, that this type of acid

detergent may have a much wider application. It has been reported to have been successfully used for practically all general cleaning in some milk plants. This particular application of acid cleaners is important, since it illustrates the possibilities for improved washing and cleaning methods which can come from intelligent ventures away from traditional methods.

(e) *Germicides*

Much of the cleaning in food processing plants is for the purpose of obtaining bacteriological cleanliness. It is therefore important to consider methods and materials which are useful in reaching that end. Of first importance is the obtaining of thorough physical cleanliness. Physical cleanliness can be obtained, however, without necessarily having bacteriological cleanliness, so it is only natural to attempt to combine some germicidal agent with the cleaning solution in order to accomplish both physical and bacteriological cleanliness in a single operation. Attempts to achieve this result have not been entirely satisfactory, but some progress has been made in that direction in recent years.

One of the simplest methods of obtaining germicidal action during the washing process is to maintain the wash solution at such a high temperature that it can destroy the microorganisms. Such a method can be used for some types of work but there are many cases in which temperatures high enough to destroy the microorganisms are too high to obtain good physical cleaning, are detrimental to the object being cleaned, or are dangerous to the operator. In some cases, too, it is difficult to obtain sufficiently high temperatures.

Another plan for obtaining bacteriological cleanliness along with physical cleanliness is to use a cleaning material which possesses germicidal properties. The widest used application of this idea is in the use of strong caustic soda solutions for bottle washing in the milk industry and the carbonated beverage industry. Such highly caustic cleaning solutions are not suitable for all applications, and especially cannot be used where hand cleaning has to be resorted to.

Until recently, attempts to provide other germicidal detergent solutions suitable for use in the food industries have not yielded promising results. Many chemicals which possess germicidal properties do not function while in the presence of the kind of chemicals which have been used as detergent substances, nor under the conditions under which the cleaning has been carried out. For instance, hypochlorites which, when properly used, give excellent germicidal results are not very suitable for use in detergent solutions for the reason that the available chlorine is quickly dissipated by the soil in the solutions, and by the heat in case high temperatures are used. Furthermore, the germicidal effectiveness of the hypochlorite is markedly decreased by the high alkalinites used, and is sometimes adversely affected by other components of the cleaning solution. Then, too, some germicidal materials, even if they could work under the conditions of cleaning, would not be acceptable in food industries because of their poisonous nature or because of a possible deleterious effect upon the taste, color, or other quality factors of the food being processed.

Recent studies made with new or different chemical materials than those considered in the past have involved a more critical study of the conditions of use, and were not hampered by too close adherence to traditional lines of practice. They show promise of providing at least several different ways of obtaining bacteriological action during the actual cleaning process. The acid detergents referred to above are one example. There are a number of newly described surface-active agents which, under suitable conditions of use, possess not only excellent detergent properties but also very good germicidal properties. So far, only a few of these materials have been given even preliminary tests in food plants. There is little doubt, however, but what many will prove to be very useful in this field.

A number of phenolic derivatives and also certain new types of available chlorine compounds, some of which are referred to as *N*-chloro compounds, have been described recently in the literature. Some show promise of being suitable for use in detergent solutions, since they are not rapidly dissipated by the organic matter present in the soil as are the ordinary hypochlorites. The full potentialities of these newer materials will not be realized without proper attention to the selection of the conditions under which they are to be used and a selection of suitable materials to be used in conjunction with them. It is well established that the germ-killing action of some of these materials can be considerably enhanced by the presence in solution of other materials which in themselves may or may not be germicidal. Suitable application of this synergistic principle in the combining of detergent and germicidal materials will enable one to obtain the desired bacteriological cleanliness with the use of less germicidal material than would otherwise be possible. Since many materials become much less effective when used at the wrong *pH*, it is important to select the proper *pH* and to control the method so as to maintain the *pH* at the optimum point during the whole cleaning operation. This involves the selection of suitable buffer materials to be used in the detergent solution.

Because germicidal detergent solutions appropriate for many needs have not been available, it has been customary and necessary to obtain the required bacteriological cleanliness by separate means after the physical cleanliness has been obtained. Sometimes this bacteriological treatment is carried out in the regular rinse operation, and sometimes in a separate operation after the wash solution has already been completely rinsed from the surface.

Here, again, heat is one of the best methods of obtaining a bacteriologically clean surface. Usually it is advisable to have the washing solution completely removed by a prerinse before attempting to apply the bacteriological rinse, whether it be a heat or chemical type of treatment. However, in some cases the bacteriological rinse is the only rinse used. Heat may be applied by carrying out the rinse operation with water of sufficiently high temperature to bring the surface to a high enough temperature for a long enough time to kill the microorganisms. In other cases, heat is used in the form of steam which is applied to the surface by blowing from a suitable nozzle or, in the case of piping and other equipment which can be connected directly to the steam line and closed off, by running steam into the equipment and maintaining it at a suit-

ably high pressure for a proper length of time. The effectiveness and the length of time required for obtaining good results by the use of steam will vary with different types of equipment because of differences in heat capacity and other factors.

In some cases, when the nature of the surface being cleaned is such that it is not practical to use hot water or steam for obtaining bacteriological cleanliness, chemical methods are used. The chemical generally used for germicidal rinse purposes is active chlorine, usually in the form of a hypochlorite. Chlorine can kill microorganisms in very low concentrations in very short periods of time. It has the disadvantage, however, of being easily dissipated by even small amounts of organic matter which may be present. For this reason it is usually recommended that the rinse solution be tested frequently so that the concentration of the available chlorine can be kept at about 50 p. p. m. during the time of use. There is a further disadvantage in the use of chlorine in that it is harmful to some types of equipment because it is corrosive. Some of the hypochlorite compounds are not stable, either. However, it is probable that chlorine will continue to be the most widely used germicidal material for a long time to come. There are many different hypochlorite preparations on the market, the best way to use each varying with the particular product used and the job to be done. In general, the recommendations of the manufacturer should be followed. Intelligent use should also be made of such other information as may be obtained from the literature and from personal experience in the particular application.

There has been some progress made toward obtaining chlorine compounds which furnish available chlorine in sufficient concentration to be destructive to micro-organisms and which are still stable enough not to dissipate their available chlorine on many types of organic matter. Chloramine-T and chloramine-B are two compounds representing a step in this direction. Further progress in this direction is represented in the compound, azochloramid, which, although stable in the presence of most types of organic matter, is still a very potent germicidal material. Other available chlorine compounds are described in the literature. So far, these newer materials have been too costly to compete successfully with ordinary hypochlorites except in certain special applications; but some of them deserve more attention than they have received and should prove especially useful in certain types of cleaning problems in the food industry where contact with organic matter is unavoidable.

Some surface-active materials are being tested for germicidal rinse purposes. Considerable work has been done with quaternary ammonium compounds which, under proper conditions, exert bacteriostatic and germicidal properties in very dilute solutions. Many promising germicidal materials are being developed, but it will probably be a considerable length of time before the best methods of practical application of these materials are found and their cost becomes low enough to permit their wide usage. Many worthwhile methods should come from work in this field.

(f) Proprietary Products

In the tables and discussion above have been mentioned various chemicals which are useful in cleaning and sanitary operations. It so happens, however, that for most

cleaning operations the optimum results cannot be obtained by the use of a single chemical material. The use of combinations of properly selected substances mixed in correct proportions to give a cleaning solution which will be best adapted for the particular purpose in mind is required. Some of the larger food processing plants may find it possible to take advantage of these optimum combinations by keeping on hand a supply of all the various raw materials required. In such instances, special maintenance men are necessary to make up the particular preparations to be used for the various purposes throughout the plant. For many plants, however, it will be found more satisfactory to purchase proprietary materials which have been developed and prepared by organizations which make a special study of the particular types of washing and detergency problems involved. The cost per pound of such cleaning materials purchased from a reliable and progressive firm specializing in this field may seem somewhat high compared with the cost of some of the more commonly used detergent chemicals. The cost of the cleaning materials used on any particular cleaning job usually represents but a small fraction of the total cost of doing the job. Labor generally represents the biggest proportion of the cost. Steam and hot water expenses often are relatively large, too. Such savings as can be made by paying slightly less per pound for the detergent usually represents a very small fraction of the total cleaning cost and may be entirely insignificant in comparison with the gain which may come from the service rendered by such a firm. Such service, in addition to supplying an efficient product and demonstrating how best to use it, may result in the improvement of the various cleaning operations in such a manner as to cut down on the total time and labor involved. It may also bring about a reduction in losses commonly caused by damage to equipment and spoilage of food batches when wrong cleaning materials or methods are used. The advantages to be gained from these services usually far outweigh any increase in cost of the cleaning materials used. Sometimes the cost of the total materials used will actually be less if the food manufacturer avails himself of such services than if he attempts to do the job without expert advice by using materials not properly selected for the requirements.

6. Selection of the Product

A wise choice of the cleaning material to be used rests upon the careful consideration of a number of factors, among which the following are important:

1. The particular cleaning job for which the detergent is to be used and the method to be employed in its use.
2. The cost. All too frequently in considering the cost angle the prospective buyer looks only at the cost per pound of the detergent available. Cost per pound is no infallible criterion by which to judge the value of the cleaning material for a given purpose, and is valid only in case one is comparing the cost per pound of identical materials available from different suppliers; even then cost should not be the sole basis upon which to choose a source of supply. The real cost angle to be considered is the net cost of accomplishing the cleaning job which is to be done. This net cost includes

not only the cleaning material to be used, but also the labor, the cost of other supplies such as hot water, brushes, and other auxiliary aids, the effect upon the life of the equipment, and the quality of results obtained. One cleaning material may be very low in cost per pound and yet be more expensive to use than a chemical which may cost several times as much per pound. The low-priced product may require more labor, be more detrimental to the equipment being cleaned and the auxiliary equipment used for cleaning purposes, and require much greater cost from the standpoint of water used. Since, in most cleaning operations, the cost of the cleaning material itself is a minor proportion of the total cost of doing the job, these other expenses must be taken into the picture if one is to have a sound basis for comparison. This is true for the reason that other costs are to a considerable extent influenced by the detergent action of the material selected.

3. The source of supply should also be given careful consideration. Assuming equal quality of cleaning materials themselves, and equal price per pound, a choice of the supplier to be selected depends upon such factors as the reliability of the supplier, the types of service he will render, and the capacity of his plant to supply the requirements, not only immediately but over a period of time. Since it takes considerable time and money to train employees to do an efficient job of cleaning and since the best methods for getting results with different cleaners will vary somewhat, it is desirable to change cleaning materials as infrequently as possible once the materials and method have been found which give the desired results in an economical manner. Therefore, it is wise to purchase from a concern which will be able to supply the total requirements for that particular cleaning material over a long period of time. Naturally, also, it is desirable to purchase from a firm which is progressive and alert in taking advantage of improvements which become available from time to time and in rendering a general service in the field which it covers.

II. SANITATION AND PLANT HOUSEKEEPING

Under the heading of plant housekeeping will be considered those administrative factors which are necessary to obtain the desired sanitation and plant cleanliness. Under the heading of sanitation will be considered several important factors aside from administration, such as plant and machine design, cleaning operations, germicidal methods, and cleanliness of workers, product, and containers.

1. Sanitation

(a) *Machine and Plant Design*

Let us consider the building of equipment first. In spite of the fact that sanitation is one of the most important factors upon which depends the success of any food processing industry, the requirements of sanitation have been taken into consideration far less than they should be in the planning and designing of machines and

plants. See page 162. Each piece of equipment should be designed not only from the functional standpoint (what it is to be used for), but also from the maintenance standpoint, (what must be done in the way of keeping it in a clean and sanitary condition and in good operating order). A piece of equipment may be so designed as to carry out the processing functions in a perfectly satisfactory manner, but of such design that an undue amount of time and labor is required to keep it in a clean and sanitary condition. The design of the machine should be made as simple as possible, and all parts should be as accessible as possible for cleaning. For those parts that have to be taken down for cleaning, the design should be such that the time required to take down and put together is as little as possible, and that the possibility of mistakes in reassembling are reduced to a minimum. The contour of the machine and its parts should be as smooth and streamlined as possible to avoid sharp indentations and corners difficult to get at for cleaning purposes. Furthermore, in the design of the equipment, the specifications should call for materials which will be as easy as possible to clean and as resistant as possible to the cleaning methods which will have to be used. For instance, if equally suitable from other standpoints, it is more desirable to construct those parts of the equipment which are to be cleaned from a stainless steel than from aluminum, which is easily damaged by many cleaning materials. In like manner, suitable metals or impervious plastic materials are more desirable than wood.

The design and construction of the building can have much to do with the ease and efficiency with which a proper housekeeping and sanitation program can be carried out. The building should be designed from the standpoint both of the process to be carried out and of the maintenance required to keep the plant in suitable sanitary condition. This involves such factors as simple design, suitable contours to avoid corners and other places difficult to clean, and selection for all surfaces of suitable nonporous materials which are easy to clean and maintain and able to withstand satisfactorily the necessary cleaning methods. The construction of the building and equipment should be such as to provide as little chance as possible for the harboring of rats, mice, cockroaches, and similar undesired infestations. The windows and doors should be properly screened to keep out flies and other carriers of microorganisms.

The maintenance of sanitary conditions throughout the plant can be greatly facilitated if the plant is provided either with complete air conditioning or at least with a suitable air circulating, filtering, and air washing system for keeping air-borne dust and microorganisms at a minimum. Some plants nowadays use ultraviolet radiation as a further aid to minimizing contamination by microorganisms. The ultraviolet radiation may be used in certain local areas, as, for instance, in the rising room or over the bread wrapping machine in a bakery. With suitable filters to protect the eyes of the workmen from direct radiation, it may be used over large areas, or it may be used in concentrated form in the ducts of the air circulating system or in special concentrated radiation chambers connected therewith. There have been recent reports of the successful use of certain organic vapors, such as those of propylene glycol, as a means of destroying air-borne microorganisms. This whole field of air sanitation is

still in a pioneer stage, and many useful developments may be expected from future studies.

The lining-up and placing of the equipment in the building and the flow of processes also have a bearing on the ease and effectiveness with which the cleaning program can be carried out. There should be ample room around all equipment, not only for ordinary working purposes, but also to make it easy to get at for cleaning.

Another factor of importance is proper lighting. The light should be good and so distributed that there will be no dark corners in which it is easy to overlook the presence of dirt. The lighting arrangement should be such that no part of the equipment is in deep shadow.

There should be ample provisions made for hot and cold water supplies and connections, properly placed floor drains, and convenient electrical outlets for the use of electrically operated cleaning aids.

There should be provided at locations convenient to each department ample toilet and washroom facilities for all employees, even during times of peak loads. These facilities should be such as to encourage the utmost in cleanliness on the part of every employee. Even such a seemingly minor item as the type of soap provided in the washrooms can materially influence the extent to which employees will utilize the hand washing facilities provided.

(b) Personnel

Even though the building and equipment are maintained in a perfectly satisfactory and sanitary manner, the business would not be assured of success from a sanitary standpoint without equal consideration being given to the personnel, namely, the operators who handle the product and the machines used in the processing. The extent to which uncleanliness in the person or in the uniforms of the various workers will affect the product will, of course, depend upon the particular operation in which the individual is involved. In some operations, it is essential that the workers be as clean and careful as possible in regard to personal sanitation and the sanitary condition of their uniforms, while on other types of jobs even relatively unsanitary workers may have little effect on the quality of the final product. However, from a psychological and managerial point of view, even if not required from a strictly technical necessity, it will pay to endeavor to keep all workers at a high standard of cleanliness. Micro-organisms may easily be transmitted from a careless person to the food product even though that individual has no direct contact with it. This contamination can easily come about by the transfer of microorganisms from the careless person onto the equipment which he handles and which in turn is handled by one or more other people, and finally by some person who does have direct contact with the food being processed. Such innocent appearing objects as doorknobs, handrails, truck handles, etc., can easily be the vehicle for transferring the organisms from one individual to another and thus eventually to the food product. Care should be taken that such methods of carrying organisms do not result in causing contamination, not only directly from the

workers of the plant, but from outsiders who come to the plant as visitors or for business purposes. For instance, the truck driver, the delivery man, electricians, and other service men, or even the office help who come to the plant on errands, may be the means of starting the chain of contamination which can finally lead to the product itself.

It is important to maintain good sanitary conditions throughout the whole plant, for factors such as those just mentioned may be the means of providing the links in a chain of transmission of microorganisms from some unsanitary source to the production line. It is important also to clean at frequent intervals such articles as may serve as links in the contamination chain, especially those coming in contact with outside personnel.

(c) Product and Container

In many cases, the cleaning and sanitary operations are concerned with the product itself. Here the choice of methods will of necessity be limited to such materials and methods as will cause as small an adverse effect upon the product as possible. Furthermore, it is important not only to put this product into a suitable sanitary condition, but also to see that it does not thereafter pick up contamination from contact with either personnel or equipment with which it must come in contact in further steps of the process.

The container into which the product is finally packed for storage and shipment must of course be in a suitable sanitary condition if the product is to arrive in the hands of the consumer in a satisfactory state. All the expense of maintaining a sanitary plant, equipment, and personnel would go for naught if the perfect product were put into imperfect containers. The importance of the sanitation of the container will vary, naturally, with different food products and different processes used. For instance, for canned foods which are subject to high-pressure steam sterilization after the food is sealed in the cans, the cans would not necessarily have to be sterile before food is put into them. Naturally such containers should be physically and chemically clean so as not to spoil the quality of the product. It is of course desirable to have them as nearly bacteriologically clean as is necessary and practical; but the bacteriological degree of cleanliness would not necessarily, in that case, have to be as high as for a product not subjected to sterilizing processes after being packed. The nature of the product itself will have something to do also with the degree of cleanliness which will be required by the container in which it is packed.

(d) Selection of Methods

We have already considered various types of chemicals which can be used for cleaning purposes together with some of the factors influencing the cleaning operation. In plant practice it will be found that different methods and different cleaning materials should be used in order to get the maximum efficiency for different cleaning jobs. Much help in the selection of methods and materials can be obtained from detergent

manufacturers. However, because of many varying conditions, no two plants have exactly the same cleaning problems. What proves, therefore, to be best in one plant will not necessarily be best for use in another plant, although it may prove to be the starting point or basis from which one can proceed by intelligent trial and error to find the most satisfactory method for the operation in question.

In general, it will be found that the cleaning action of the cleaning solution will be greatly aided by intelligent use of friction, usually in the form of mechanical aids or high-pressure sprays. Merely flushing off the surface will not provide as good detergent action as can be obtained if the solution or rinse water is driven onto the surface at a very high speed from a suitable nozzle operating at high pressure.

The promptness with which cleaning is carried out after the object has been soiled is also an important factor, in many cases, in obtaining a good result economically.

The frequency of cleaning will depend upon the particular material being processed, the nature of the equipment, and the nature of the processing being done. Where equipment, after being cleaned, has to stand a number of hours before being used again, it is good practice to subject it to a germicidal rinse immediately before use so that any contamination which may have come onto it in the meantime will be eliminated.

(e) *Bacteriological Cleanliness*

Where bacteriological cleanliness is required, special methods generally must be used. It has already been pointed out that, as a basis for obtaining bacteriological cleanliness, one should first of all obtain a good state of physical cleanliness, for without that bacteriological cleanliness is more difficult, and in many cases impossible, to attain. There are many different methods for obtaining bacteriological cleanliness. Most of them, however, can be considered as being based upon the use of one or the other of two general principles, namely, heat or radiant energy, and chemical action.

Before considering the methods of obtaining bacteriological cleanliness let us note some of the factors which should be kept in mind in the practical application of various bactericidal methods. Among these factors are:

1. The types of microorganism involved.
2. Whether they are wet or dry.
3. The kind of killing agent used: heat, light, chemicals, etc.
4. The temperature of application.
5. The time of application.
6. Cleanliness of the surfaces and solutions involved.
7. The type of surface or medium harboring the microorganisms.

Radiant Energy.—Heat as a method of obtaining bacteriological cleanliness is very satisfactory if properly used. The factors to be considered are the nature of the organisms, the nature of the surface to be sterilized, and the nature of the heat available. In cleaning many types of equipment, steam sterilization is practiced. There is a special advantage in using steam instead of dry heat for sterilization—

most microorganisms are much more subject to damage by heat in the presence of moisture than to heat in the absence of moisture. The chief reason for obtaining unsatisfactory results with the use of steam comes from the failure to bring the surface being cleaned to a high enough temperature and to maintain it at that temperature for a long enough time. Very often the difficulty involved in bringing the surface to a killing temperature is entirely overlooked. The object may be subjected to the action of the steam for a time which is longer than theoretically would be required to kill organisms; but it may be, and often is, the case that the surface of the object upon which the organism rests may in that time never really reach the temperature of the steam or a temperature high enough to destroy any great proportion of the organisms which may be on the surface. The heat capacity of some pieces of equipment is large; and while the temperature of the steam may be very high the time of contact may be too short to bring the surface up to the required temperature. Furthermore, in some cases, the loss of heat through the equipment can be so great that it is impossible really to get the surface to the desired temperature in any reasonable time or with an economical amount of steam.

In cases where the equipment can be connected in an airtight manner to the steam line and the steam allowed to flow through under pressure, as, for instance, in the cleaning out of a pipe line or a pressure vessel, the steam has a much better opportunity to do its work than when merely blown onto the surface, as is frequently done in cleaning tanks and other pieces of equipment.

Some types of surfaces, however, do not lend themselves to steam sterilization because of the fact that the high temperature is detrimental to them.

Another method of obtaining bacteriologically clean surfaces, involving the use of ultraviolet radiation, has been receiving some attention in the last few years. Micro-organisms are especially sensitive to certain wave lengths in the ultraviolet region. For some purposes, suitable application of ultraviolet rays can yield good results. Certain properties of this type of radiation must be kept in mind, however, in attempting to utilize it. Ultraviolet rays have very little penetrating power, so that even very thin films of dirt or moisture may shield the microorganisms from the damaging effect of the radiation. Furthermore, the shape and contour of the surface being radiated and the position of the source and direction of radiation must be such that no areas are shaded or shielded from the direct line of radiation from the ultraviolet source.

Considerable work has been done in the use of ultraviolet radiation for the bacteriological purification of air. Much of this work has involved the sterilization of air in hospital operating rooms and schoolrooms, but there has also been some work done in the direction of applying this idea to air conditioning for industrial purposes. For example, ultraviolet radiation is being successfully used for control of mold growth in the bread rising chambers in bakeries and for protecting the bread during slicing and wrapping operations. This development deserves attention from such plants as can benefit from bacteriologically conditioned air.

There are a few reports in the literature concerning the germicidal effects of another

type of radiation, namely, ultrasonic radiation, but so far this has not reached the stage of practical application in the food industry.

Chemical Action.—Because it is not always possible or desirable to employ steam or other radiation methods, there have come into use a number of chemical sterilizing methods. In general, most of these consist of aqueous solutions of some particular active chemical which has a sufficient germicidal action to destroy the microorganisms. One of the most widely used is chlorine or chlorine compounds, usually in the form of hypochlorites. Active chlorine, even at very low concentrations, will destroy microorganisms in a very short period of time. As has already been mentioned, hypochlorites possess a major disadvantage in that they will attack many types of organic matter besides the microorganisms. This means that they can damage some types of equipment. Worse than that, it means that, if the last traces of soil are not completely rinsed off before the hypochlorite rinse is applied, there is danger of not obtaining the desired germicidal results. However, in spite of this disadvantage, when properly used these materials can give excellent results; and chlorine and the hypochlorites remain the most important chemical bactericidal agents in the food processing field.

Many chemicals which possess germicidal activity are not practical for use in the food field for several reasons. Some are of poisonous nature and therefore should not be used where there is danger of carry-over and contamination of food products. Others may not be poisonous but may have a detrimental effect on the taste, odor, color, or keeping qualities of the product in question. Some of the materials may be corrosive to the equipment. Other materials may be precipitated out by traces of soil and not be usable from that standpoint. Attention has already been called, though, to a few other types of germicides which appear to hold considerable promise of being useful for many applications of importance to the food industries. Many of the newer types of products will require different methods and conditions of use than the old. Until these methods are more clearly defined and until plant operators are willing to consider methods other than those which have been time-honored, the benefits to be derived from the use of these materials will be limited.

Degree of Bacteriological Cleanliness.—So far little mention has been made of the degree of bacteriological cleanliness required or how to determine whether or not this degree of cleanliness has been achieved. The exact standards of cleanliness required will differ for different food products and processes. There are two general methods of checking the degree of bacteriological cleanliness achieved. These are not absolute; and the exact way in which they can best be applied will also vary with the food and process concerned.

One method is an examination of the surfaces which have been cleaned for the presence of live microorganisms. This may be done by suitable swabbing or contact plate methods; and while these methods probably do not show the total number of live microorganisms on the portion of the surface examined they are capable, when properly and regularly used, of serving as an indication of the relative cleanliness of the surface.

A second method of checking on whether or not the cleaning and sanitary work is satisfactory is more indirect; it does not give an absolute answer either, but is nevertheless very useful. It consists of testing at regular intervals the bacteriological quality of the product being produced. If the product continues hour after hour to be of high bacteriological quality, then it would appear that the cleaning was satisfactory. If, however, the bacteriological quality of the product is not up to standard, this deficiency in quality may or may not be due to improper cleaning. It is possible that the cleaning operation may be entirely satisfactory and that contamination may be coming in from some outside source, from the air, for instance. On the other hand, it may be that the cleaning operations are satisfactory on all pieces of equipment except for one, which is improperly cleaned and therefore contaminating the whole product. Information concerning such possibilities can be obtained by examining samples of the product after each step in the processing so as to determine at what point the contamination of the product occurred. Such an examination may reveal that the contamination enters almost entirely at one particular stage, or it may show that the contamination builds up gradually throughout the whole operation. If the contamination appears to enter almost entirely in one stage of the operation, one naturally would look to that stage for the source of the trouble. In cases where the contamination builds up gradually throughout the whole process, it may be that improper cleaning at all stages is responsible for the trouble.

Mention has already been made of the importance of having building and equipment design and construction of such a nature as to provide as little as possible a chance for the harboring of infestations of rodents (see page 267) or insect pests (see page 245). Good design and construction are in themselves, however, no guarantee against some such trouble, especially where careless sanitation and plant upkeep are allowed. Scrupulous cleanliness everywhere throughout the plant, and a prompt, vigorous, and intelligent campaign of eradication at even the first signs of infestation, are necessary in addition to favorable building and plant construction to insure freedom from all the various forms of life which attempt to establish residence in food plants. In case infestation has been allowed to occur, the best method of eradication to be used will depend upon the type of animal or insect involved, and the location and extent of the foothold it has gained. The first step is identifying the pest and definitely locating all plant areas harboring it. Government bulletins and other similar publications are available giving detailed and proved methods of eradicating practically all types of infestations by animals and insects. A method suited to the particular case at hand should be put into use promptly to avoid further spreading of the infestation. At the same time, the source or origin of the original infestation should be located if possible and steps taken to prevent a reinfestation. In some cases, especially in old and poorly constructed plants, when it may be impossible to eradicate the pests completely, a continuous campaign against the pest should be maintained to keep the pest population to as low a figure as possible. In many cases, too, a continuous campaign will be required because it may not be possible to prevent the con-

tinuous entry of pests from outside into the plant. In all cases, however, a high degree of plant sanitation will help to minimize the difficulty.

It is important, naturally, to consider the cost of the cleaning and sterilizing methods which are adopted; but in doing so, it should be remembered that the small saving which can be made by being penurious in respect to these two operations may be lost many times over by the partial or total loss of even a small percentage of the product through spoilage brought about by improper sanitation.

2. Plant Housekeeping

In this section we shall discuss the administrative side of the problem of cleaning and sanitation. One of the first prerequisites to a successful plant housekeeping program is the full realization by the management of the sanitary requirements for successful operation of the plant, as well as the desire to maintain a high standard of sanitation throughout the whole plant. In addition to the realization of the need of, and the desire to, maintain such standards, the management should also have a general understanding of the various factors involved and considerable detailed knowledge concerning ways of administering such a sanitary program.

The success of any sanitary program will depend upon the personal attitude of the employees, especially of the minor executives and foremen, toward the program. From the management point of view, therefore, the execution of this program depends to a large extent upon the ability to create and maintain proper attitudes and relationships among all the employees on this matter. This involves personnel management and a well-planned educational campaign both to keep employees continuously conscious of the need for proper sanitation and to create a real desire on the part of all concerned to achieve this. One educational goal should be getting each workman to take a pride in the cleanliness of the plant as a whole and particularly in that part with which he personally is concerned.

The success of a sanitation program depends much upon the organization setup for carrying out the details of the program. Only in the smallest plants will the management itself have time to supervise personally the details of the execution of this program. In general, the carrying out of these details will have to be left to various minor officials and plant personnel. However, there should be a delegation of responsibility and authority for carrying out the operations necessary to get the desired results. Furthermore, there should be a regular follow-up from the management on down, to see that these responsibilities are lived up to and that no one gets by without doing his or her job in the approved manner, whether it be supervisory or the simplest of the actual cleaning operations.

Details regarding those to whom authority and responsibility should be delegated and which employees should do the actual cleanup and sanitary maintenance work will vary from plant to plant, depending upon the local conditions. A system which works well in one plant may not be adaptable in others. Since, however, cleanliness and plant sanitation are very closely connected with the quality of the product put out and

with the production capacity, it would seem that the responsibility for the cleanliness should, in general, rest in the hands of the individual responsible for the production of the product. In most plants there will be several different processes or departments; and the responsibility for the sanitation and upkeep within that department might well be placed on the shoulders of the foreman of that particular department; he in turn can delegate this work to his group leaders in whatever fashion will be most effective in maintaining the standard of sanitation required for his department.

The question of the personnel doing the actual cleaning and maintenance work will also vary with the plant and the particular part of the plant involved. As a general rule it is better, wherever possible, to have the men who use the equipment do the cleaning under the supervision of their immediate foreman, who should be responsible for checking to see that the cleaning is properly done and the equipment is in suitable sanitary condition before it is put back in use.

For certain general maintenance work throughout the plant and for cleaning certain specialized equipment, it may be necessary to have a special sanitary crew to look after, and attend to, these special phases of the cleaning and sanitary work. To whom these special workers shall be responsible will in turn depend upon the particular work they do. If they are engaged in cleaning special equipment, then they should be responsible to the foreman in charge of such equipment. If, on the other hand, they are to be engaged in general janitorial and sanitary maintenance work on the building and throughout the plant, they should be responsible to the plant manager or other executives who in turn have the responsibility of all that area of the plant. The exact details of the administrative organization of the program are not so important as long as there really is a program and a real effort made to carry it out. In other words, the cleaning and sanitary upkeep should not be left to the haphazard whims of the individual workmen.

There should be provided certain standards of cleanliness and certain established methods of maintaining these standards in all of the various departments of the plant, as well as methods of checking up to see that these standards are met. Just what the standards shall be, what materials and methods are to be used to maintain them, and how the results can best be checked will again depend upon the plant and the particular department of the plant involved. However, it should be the responsibility of one of the executive managers of the plant to see to it personally, or through a properly delegated subordinate, that such standards are set up, that suitable methods for achieving the desired results are devised, and that chemicals and equipment for carrying out these methods are on hand when and where needed. It should be this same executive's responsibility to see that, at suitable intervals, the work of his subordinates is checked against the requirements for the various departments. It should further be the responsibility of this executive to see that either he or someone delegated to the task shall keep up to date with improvements in materials and methods which become known through the work of the others interested in this field, and to do what experimenting is required in the way of adapting the improvements to the company's own requirements.

Assuming that the personnel organization for the cleaning and maintenance work has been set up properly, the responsibility delegated, and the standard methods established, the efficiency with which the setup will work will depend upon a number of other factors, some of which may be worth mentioning.

There should be a time schedule for cleaning which should be adhered to as closely as possible. The nature of this schedule will vary from department to department and with the nature of the particular tasks involved. Some parts of the plant will need almost continuous attention from the plant housekeeping and sanitary standpoint, whereas other parts will require only periodic attention, such as daily cleaning, and in some cases will need cleaning at even less frequent intervals. Furthermore, all the materials, tools, and equipment needed for each cleaning operation should be kept at a place convenient for their use so that there is no excuse for not doing the job properly at the time it should be done. Every item, not only of the cleaning equipment, but of every other type of equipment and material in the plant, should have a definite place to be kept when not in use. Certain individuals should be responsible for seeing that the equipment and material are always at their appointed place when not in use. Much also can be done to improve the sanitary conditions in the plant if the policy is followed that there shall be no miscellaneous and surplus or unusable materials or equipment left scattered around the plant: If the equipment is usable it should be kept in its proper place; if it becomes broken down or unusable the parts should not be left scattered about but should be assembled and taken to the repair shop, or disposed of in some other manner.

A part of the training, not only of the maintenance men but also of all the workmen in the plant, should involve the development of a spirit of alertness by the employee in observing and reporting anything wrong in the equipment, process, or product. Prompt reporting of slight defects in equipment or minor breakdowns to the foreman responsible for the operation of the department may enable that foreman to have these defects taken care of promptly and perhaps avoid possible shutdowns and expense of major repairs which will develop if the minor defects are not promptly rectified.

It may sometimes help in maintaining a high standard of plant housekeeping and sanitation if there is set up a system of scoring the various departments of the plants on their cleanliness and sanitary conditions. This can serve as a stimulus to the maintenance of a proper degree of plant sanitation by a friendly spirit of competition between various departments and by a justifiable pride in results obtained. This, of course, is again a matter of personnel management.

The plant housekeeping department will, in addition to the ordinary cleaning and sanitary activities, sometimes be responsible for such equipment maintenance work as oiling, inspection, repairs, and general upkeep of the equipment, and such building maintenance work as periodic painting and minor repairs. In many ways such functions rightly belong in the hands of those responsible for the plant sanitation and plant housekeeping, since they are closely related. For instance, the type of cleaning materials used in washing the walls and floors will have a great deal to do with the matter of the time expiring before these surfaces will have to be resurfaced by painting or by

other methods. Also, the type of painting and the quality of repair work done will have much to do with the ease with which the cleaning and sanitary part of the plant upkeep can be carried out.

III. SUMMARY

The importance of high standards of cleanliness and plant sanitation has been pointed out, together with some of the reasons for this importance. The general principles of, materials and equipment available for, and factors to be considered in cleaning and sanitation in the food processing plants have been discussed. The importance of setting up a proper system and properly defining the responsibilities for the carrying out of that system and other considerations involved in the administration of a sanitary and plant housekeeping program have been presented. Mention has also been made of the necessity for taking sanitary requirements into consideration when designing, building, and operating equipment and plants for the processing of food products.

Space has not permitted a detailed discussion of the many important individual problems concerned in this essential activity of food processing plants. Much detailed information is available from the scientific and trade literature and much first-hand information of value can be obtained by discussion of these problems with other plant operators and with representatives of reliable firms dealing in equipment and materials for use in food plants. The bibliography attached to this chapter is not by any means a complete bibliography on the many subjects of interest. Rather, it is an attempt to give ready reference to a few of the articles which have appeared in recent years. From these references and the indexes in the journals from which they are taken, the reader will find no difficulty in locating many other articles of value.

It should be understood that this field is not a static one, but one in which there is a continuous flow of new ideas and new methods. Many may prove to be of little permanent value; but some will represent marked advances. Keeping abreast with these developments will be necessary in order to obtain at all times the best sanitary results in the most economical manner.

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Chapter VII

INSECT CONTROL: INSECTICIDES AND FUNGICIDES

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I. INSECT PESTS OF FOOD PRODUCTS

Food products are subject to attack by insects and related vermin. The injury may consist in actual destruction of material or it may involve chiefly contamination to render the product unfit for human consumption. Insect damage should be avoided both in consideration of public health and in maintaining consumer confidence. Protection is required for both raw materials and finished products, and should be uninterrupted in the course of the different processes of manufacture, as well as during the various periods of transportation and storage.

The principal classes of stored foods affected by insects are: cereal grains, whole and ground; leguminous and other seeds and their oil-free products; cured animal products, as dried meat products or scrap, and egg powder; cured dairy products, as milk powder and cheese; dried fruits; and shelled nuts.

Just as with human beings, foods vary in their attractiveness to insects. Some are nearly free of these pests, others must be guarded continually against the depredations of characteristic species. Certain active insects, such as cockroaches and ants, with an instinct for traveling widely and rapidly, are not confined to a particular type of food, but the variety of their diets compensates for the single balanced foodstuff chosen by insects with more restricted appetites and mobility. Different grades of sugars, starches, and other purified substances will not alone support insect development. Favorable combinations of the food elements in which insect development can be completed are the different ground cereals, broken nuts, ground seed products, except those containing free oil, and dried dairy and meat products. Dried fruits, as raisins and prunes, are intermediate in their value to the insect as a developmental diet, although they are attractive to the adults of some species which gain their energy and water from this source.

1. Classification

The principal insect pests may be classified by their preferred food types as follows:

1. Pests of the cured seeds of cereals and legumes:

Grain weevils, *Sitophilus granarius* and *S. oryza*.

Angoumois grain moth, *Sitotroga cerealella*.

Common bean weevil, *Acanthoscelides obtectus* (Fig. 32, page 258).

2. Pests of processed cereals and other products high in carbohydrates:

(a) Small, reddish-brown beetles.

Confused flour beetle, *Tribolium confusum* (Figs. 34-36, page 264).

Red flour beetle, *T. castaneum*.

Saw-toothed grain beetle, *Oryzaephilus surinamensis*.

(b) Characterized by webbing left in the product by the "worm" stage.

Indian-meal moth, *Plodia interpunctella* (Figs. 30 and 31, page 257).

Mediterranean flour moth, *Ephestia kuhniella*.

3. Pests of animal products and others high in proteins and fats:

(a) In fatty and moist materials.

Hide beetle, *Dermestes vulpinus*.

Larder beetle, *D. lardarius*.

Red-legged ham beetle, *Necrobia rufipes*.

Cheese skipper, *Piophila casei*.

(b) In drier materials such as milk powder or wheat germ meal.

Black carpet beetle, *Attagenus piceus*.

Cabinet beetles, *Trogoderma ornata* and *T. versicolor* (Fig. 33, page 261).

4. Pests of damp, moldy cereals and food wastes:

Mealworms, *Tenebrio molitor* and *T. obscurus*.

Cadelle, *Tenebroides mauritanicus*.

Flat grain beetles, *Laemophloeus* species.

Black fungus beetle, *Alphitobius piceus*.

Spider beetles, *Plinus* species.

Pomace or vinegar fly, *Drosophila ampelophila*.

Grain mite, *Acarus siro*.

5. Pests having general food habits:

American cockroach, *Periplaneta americana*.

Oriental cockroach, *Blatta orientalis*.

German cockroach, *Blattella germanica*.

Housefly, *Musca domestica*.

Pharaoh ant, *Monomorium pharaonis*.

Tiny thief ant, *Solenopsis molesta*.

Silverfish, *Lepisma saccharina*.

2. Control

It is unfortunate that insect pests are frequently overlooked until they become so numerous and devastating that drastic measures are required to eliminate them. This situation is easily avoided by including a few systematic and relatively simple methods of insect prevention in the usual cleaning routine and safety precautions. It is certainly true here, if anywhere, that an ounce of prevention is worth a pound of cure. Prevention, for the purpose of this discussion, will be divided into two general sorts, the first dealing with the correction of structural faults in buildings and machinery, and the second with faults in plant housekeeping (see page 237).

(a) Structural Faults

Common structural faults include wooden floors with cracks where food wastes accumulate and lure insects, quarter-round at the junction of wooden partitions with the floor and ceiling in situations liable to cockroach infestation, driers constructed of wooden siding with grooves in which the larvae of flour moths like to spin their cocoons, hollow tile in walls and floors where grease ants can nest and cockroaches hide, and machinery enclosed when it should be open and accessible for the removal of stale crumbs. Accumulations of infested and moldy food materials underneath a storage building where they have sifted through the cracks from above, become sources of infestation of flour, etc., stored within the building. See Fig. 29, page 257. Floors and walls that may become contaminated with food wastes should be smooth, free of cracks, and easily swept, wiped, or washed. Where wash water and steam pass under a partition, the moisture will attract cockroaches. Wooden and metal trim and linings are pleasing to the eye and an aid to cleaning in a superficial sense, but should be sacrificed if they are likely to become hiding places for insects. White tile and chromium trim will not repel cockroaches and ants!

(b) Cleanliness

The term "faulty housekeeping" is not used here in the usual sense of a plant's being unswept, decorated with cobwebs, and littered with worthless debris. Of course, insects like nothing better than to have their food spread liberally over the floors, especially if it remains undisturbed there for awhile, but even after a good sweeping and scrubbing the cracks often contain enough cereal to support flour beetles, or sufficient stale milk to attract fungus beetles. To clean efficiently from the standpoint of insect control, a plant manager must understand in a general way the breeding and feeding habits of the pests likely to be a problem in his factory. For instance, dusty materials such as flour and powdered milk collect on the upper surfaces of machinery and overhead supports, locations that are frequently overlooked during the regular general cleanup. Unless cautioned to do so, workmen often neglect to sweep the floor after storage racks have been emptied. Floor drains, if not regularly flushed and steamed out, may become habitual loafing places for cockroaches. If drains become slimy they should be brushed and scrubbed with soap or lye to prevent drain flies from breeding. Neglected accumulations of fine trash, such as peanut husks, carried to the roof by a blower system, are likely to become a harborage of insects. Proper disposal of wastes such as tomato pulp in the vicinity of the plant is as important in fly control as screening the windows. Such faults can be corrected only by rigid cleanliness in out-of-the-way corners and cracks and careful attention to peculiar situations that may give rise to infestations. To insure definite results from the strict rules that should guide plant cleanliness, regular and intelligent inspections must be carried out. Bad spots can be cared for according to a regular schedule, as once a week or on the first of the month.

Compressed air delivered from a small nozzle at the end of a pressure hose of con-

venient length is an excellent means of blowing dust and larger particles of food out of cracks in walls and floors and from inaccessible parts of machinery. This method, however, may result in spreading infested and dirty material around to an undesirable extent, in which case a vacuum cleaner, either a portable machine or a fixed suction system, can be used. Insects and filth are actually taken up by the vacuum cleaner instead of being redistributed on the chance that they will be swept away later.

Dry storage for materials that normally have a low moisture content is an important phase of cleanliness. Damp, moldy cereals are attractive to a wide variety of insects that could never exist without the excessive moisture. Some species actually depend upon the fungus growth alone for their nourishment. Shipments by boat are particularly subject to moisture injury; and warehouse and basement storages require continual watching in this respect.

(c) Raw Material Infestation

If insects are to be avoided in stocks of susceptible raw materials such as corn, peanuts, or flour, only supplies which are found to be insect-free should be accepted. Then they must be kept under conditions that will prevent infestation. Frequently, to insure freedom from insects, the raw material is fumigated before or during storage, and then if it is isolated from any possible reinfestation it should remain insect-free until removed. To exclude insects entirely may be impractical. In that case the merchandise can be protected by placing it in cold storage, at least below 50° F., at which temperature most storage insects become inactive and their development is arrested. It is not good practice from the standpoint of insect infestation to stock up on more of a susceptible commodity than necessary. Fresh lots should be kept separate from older ones and the latter used up first.

(d) Treatment of Second-Hand Bags

The re-use of flour bags is a common practice that cannot be condemned too severely. The bags are patched and become leaky. Because it is the usual practice to clean them by suction, infestations occurring in seams are easily and frequently missed. Clean flour packed in these bags will not remain free of insects very long, a situation which often provokes damage claims. It would seem logical for the miller and his customer (the latter usually owns the bags) to agree to an inexpensive bag disinfection before each filling by means of heat or fumigation. Of course, the safest solution to the problem is to forbid the use of second-hand bags at all. Perhaps this will be done some day.

(e) Infestation of Packaged Goods

Low-grade, soft paper used as package stock, and careless wrapping and handling of the filled packages, may result in irreparable damage to the reputation of an otherwise high-class product. A package containing warm breakfast cereal and wrapped with moistened labels is temporarily so softened, especially at the corners, that it is

easily dented and even cracked slightly at one or more points. Afterward, in the grocery store or home, these cracks afford points of entry for small insects themselves or for the insertion of moth eggs from which the newly hatched larvae ("worms") of the Indian-meal moth (Figs. 30 and 31, page 257) work their way inside and leave evidence of their presence by spinning silk webbing in the product. Tough kraft paper glued to the box so as to seal and strengthen the corners before labeling will reduce the percentage of returned goods significantly. Cellophane and various grades of paper and cardboard protect only when they are securely sealed; even then insect species like the cadelle that have strong jaws, can cut their way through to the contents. These pests, however, are seldom numerous under conditions dry enough to provide suitable storage.

Three groups of important insect pests—ants, cockroaches, and flies—do not necessarily arrive with the raw material or live continuously within their food supply. In many establishments, most of the time spent in insect control is, or should be, allotted to seeking out the hiding places of ants and cockroaches.

(f) *Ant Control*

Those ants that are attracted to foods can be divided into two groups, the first containing the numerous sweet-loving species which enter buildings from nests in the ground outdoors, and the second the much smaller, inconspicuous reddish or yellowish grease ants (notably the Pharaoh ant) which nest in cracks inside. If an ant nest can be located, the colony may be killed by soaking it with kerosene or some other petroleum oil. A large outdoor colony, however, is more readily exterminated by fumigating it with carbon disulfide; a tablespoonful of the latter is poured into each of several pencil-size holes several inches deep punched in the nest at six-inch intervals. It must be remembered that carbon disulfide is highly inflammable and explosive. When the queen ant is killed, the strength of the colony declines, and eventually it dies out. A colony of grease ants, however, may contain numerous queens. The nests of these ants are to be found in cracks in walls, especially around window and door casings, often on the sunny side of the building or near artificial heat. It is worth considerable trouble to locate the nests because direct attack upon the colony is the most effective means of control. It is done by tracing the processions of worker ants back to their nests. Grease ants like dried whole egg; if a little of this material is placed where the ants are numerous, the line of insects carrying the bright yellow bits of egg is easily followed. When an ant colony cannot be located, a poison bait may be used as described on page 248.

(g) *Cockroach Control*

Because they require moisture as well as heat and prefer dark places, the larger species of cockroaches (the American cockroach and the oriental cockroach) often hide in steam tunnels, especially near a leak in the steam pipes where the walls are warm and wet. From these hiding places, especially at night, they roam up the pipes to favorable

feeding grounds. The smaller and more prolific German cockroach does not hide so far from its food, but remains in and around sinks, kettles, cookers, mixers, and similar equipment.

Cockroaches are a continuous problem wherever foods are handled. If all cockroaches could be eliminated from a factory—seldom completely possible—then more would be brought in shortly. Corrugated paper cartons, including empties, are often blamed, probably with considerable justice, for harboring these insects in transit. New purchases, even machinery, that come packed in paper, should not be stored near rooms that are used for processing foods or for stacking raw materials and finished products. Because the cafeteria, laboratory, and laundry are likely locations for cockroaches to live continually even in the most insect-free of factories, these should receive special periodic attention. From all over a plant, contaminated products are taken to the laboratory and dirty towels and aprons to the laundry, both thus becoming concentration centers from which in turn the insects may be carried to uninfested departments. The possible methods of cockroach introduction and distribution should be studied and provided against for each particular factory arrangement.

(h) Fly Control

Certain species of flies, of which the housefly is the most common, are attracted to foods, especially to those moist food wastes that are subject to fermentation and decay. Several kinds of blowflies are special pests in the meat-handling industries. Three lines of attack must be maintained simultaneously wherever flies are a problem. The most important and fundamental is the elimination of nearby breeding places by the efficient disposal of manure from domestic animals and by the elimination of fermenting straw, weeds, and other vegetable matter, as well as pools of water in basements and outdoors near the buildings. The second line of attack is the careful screening of all openings through which flies may enter the factory. The third is the localized control of those flies that do gain entrance, contact sprays containing pyrethrum or a synthetic toxicant being applied vigorously at least once a day, preferably at closing time. In general, sanitary precautions in the handling of foods go hand in hand with fly control.

A few species of flies actually breed in food ingredients or finished food products. The cheese skipper is one example. A more frequent pest is the vinegar fly which commonly breeds in fermenting fruit wastes, the vinegar-filled cracks of wooden equipment used in making prepared mustard, and comparable situations.

When insect infestations have been allowed to develop to what may be called population maturity, the cure differs for the most part only in requiring proportionately more energy than preventive measures. It may even be advisable to start afresh with a general fumigation of the premises, and then institute a systematic prevention schedule. It should be remembered, however, that fumigation cannot take the place of a thorough cleaning. In fact, the premises usually have to be cleaned anyway either before or after the fumigation is carried out.

II. INSECTICIDES

The use of insecticides, contrary to the common belief, should always be regarded as supplementary to the preventive measures just enumerated. It frequently has the advantage of overcoming insect depredations promptly; but such benefits are temporary, and should be accompanied by steps productive of more lasting results as, for instance, making structural changes. Insecticides must be used with care, lest they have a deleterious effect upon raw materials or finished products.

It is convenient for the present purpose to classify insecticides as follows:

1. Stomach poisons—arsenicals, phosphorus, and thallium.
2. Contact dusts—sodium fluoride, rotenone, pyrethrum.
 - (a) Dust carriers—talc, pyrophyllite, lime, borax, and similar powders.
3. Contact sprays—oils by themselves; oils with an added toxicant, as various phenolic compounds, rotenone, pyrethrum, and synthetic organic substitutes.
 - (a) Spray carriers—oils and solubilizers.
4. Fumigants—hydrocyanic acid, cyanogen chloride, chloropicrin, carbon disulfide, carbon tetrachloride, ethylene dichloride, ethylene oxide, methyl bromide, *p*-dichlorobenzene.
5. Miscellaneous—high- and low-temperature.

1. Stomach Poisons

Stomach poisons that find application in the control of pests of manufactured and stored foods are used chiefly to form the toxic ingredients of poison baits for ants, cockroaches, silverfish, mice, and rats. None of these baits, however, can be employed where there is any danger of food contamination.

(a) Ant Baits

Ants are by far the most important of the food pests controlled by poison baits, since generally cockroaches and silverfish are more efficiently suppressed by the use of sprays and dusts which kill by contact. When an ant nest cannot be located, the insects may be induced to carry a weak poison back to the colony where they will feed it to their queen and young. The poison must be in the right proportions since, if the ants become sick before reaching the nest, they will refuse to carry any more of the bait. The larger ants travel faster and can be fed an arsenical bait successfully, but the grease ants are so tiny and travel such distances from their nests that a slow poison like thallium sulfate (thallous sulfate, Tl_2SO_4) is more effective. Both types of baits are available commercially or may be made by the accompanying formulas. Sometimes grease ants cannot be attracted to the sweet thallium bait but will take a protein bait. Great care must be exercised in handling thallium compounds because they are extremely poisonous, on a par with strychnine. They differ from the latter in being tasteless and in acting slowly over a period of several days to two weeks.

ARSENICAL ANT BAIT (UNITED STATES GOVERNMENT FORMULA)

(a) Granulated sugar.....	9 lbs.
Water.....	9 pints
Tartaric acid crystals.....	6 g.
Sodium benzoate.....	8.4 g.

Boil slowly for 30 min. and allow to cool.

(b) Sodium arsenite (c.p.)..... 15 g.

Dissolve in 0.5 pint of hot water and cool.

Add arsenical solution to the sirup and stir well, then add 1.25 lbs. of strained honey and mix thoroughly.

SWEET THALLIUM ANT BAIT

(a) Water.....	1 pint
Granulated sugar.....	1 lb.
Strained honey.....	3 oz.
Glycerol.....	45 ml.

Bring to a boil, and then cool 5 min.

(b) Thallium sulfate..... 2 g.

Dissolve in 0.5 pint lukewarm (not hot) water.

Mix the two solutions and stir thoroughly.

PROTEIN THALLIUM ANT BAIT

Thallium sulfate.....	0.5 g
Peanut butter, preferably stale.....	75 g.
German sweet chocolate.....	25 g.

Mix thoroughly and put out in metal bottle caps or sections of soda fountain straws.

(b) *Phosphorus Bait*

Phosphorus bait is used successfully in the control of the larger species of cockroaches but not for the smaller German cockroach. On the contrary, it is easier to kill species of the latter with contact insecticides than the larger cockroaches. Although the industrial control of all cockroaches is largely by means of dusts and sprays, phosphorus bait could be distributed in steam tunnels and basements where the large species are likely to evade a man with a sprayer. Phosphorus bait should not be made by an inexperienced person but procured from a reputable manufacturer to avoid the fire hazard of baits improperly prepared.

2. Contact Dusts

Insecticidal powders which contain sodium fluoride or rotenone act both as stomach poisons, when eaten by the insects, and as contact insecticides on the external surface of the insects. However, it is best to apply such dusts so that the insects will be thoroughly coated immediately, and to depend upon wide application and the residual effectiveness of the insecticide to kill off over a period of days those individuals not reached at first. Since cockroaches frequently clean their limbs with the mouth, the internal effects of the poison undoubtedly unite with external contact effects in killing the insect. Dusts have the disadvantage of dirtying the floor of a room. On the other hand, the dust has considerable residual effectiveness not possessed by sprays, which should be utilized wherever possible by instructing the janitorial force not to disturb the deposit for several days. Because the dust layer should remain dry to continue to be an effective contact insecticide, these materials are not adapted for use in wet and steamy rooms.

(a) *Sodium Fluoride*

Sodium fluoride (NaF) is the most important and effective insecticide of any type for the control of cockroaches. Unfortunately it is poisonous to man and its use is

dangerous or unwise in many of the situations in food processing plants where an insecticide is required. Although it is not nearly so toxic to man as arsenic, from 5-10 g. are enough to kill a person, and small amounts ingested frequently in food or drink will induce chronic symptoms of poisoning. Since it is a white material similar in appearance to flour and other common powders, it must be labeled carefully and stored where it cannot be mistaken for food ingredients. In most places it is required that in retail packages it be colored Nile blue or some similar color as a safeguard against such mistakes. In some cities its use is forbidden near food in storage or being processed. The dust rising from the application of sodium fluoride is highly irritating to the membranes of the nose and mouth, so that persons who make a business of applying it are often obliged to wear dust masks. Because it is a little slow in its action on insects, it is frequently mixed with 25-50% pyrethrum powder. The pyrethrum acts rapidly to stun and paralyze the insects, but the fluoride assures their death.

(b) *Rotenone Dusts*

Rotenone and several rotenoid compounds are the toxic principles of derris, cubé (pronounced kew-bay), and timbo. Derris is a plant native in the East Indies and Malaya, the dried roots of which were imported in large quantities until war interrupted this business early in 1942. The roots of similar plants from South America contain the same insecticidal principles and are shipped from Peru as cubé and from Brazil as timbo. The roots, powdered and diluted with an inert carrier to give a rotenone content of 0.5-1%, produce good results in keeping down cockroaches. Although the action of rotenone is slow it is effective within a few days. One important advantage in its use is its safety near foods. Another advantage is the residual toxicity of the dust deposit to insects, not so great as that of sodium fluoride to be sure, but considerable when compared with the oil-base contact sprays. Rotenone is, on the whole, a more dependable insecticide than pyrethrum, but its slow action is an obstacle in those trade fields in which quick performance has been emphasized ahead of the final kill. It should be noted here that for insects in general the ultimate kill obtained by a given insecticide does not necessarily bear much relation to the speed of paralysis or "knockdown."

(c) *Pyrethrum Powders*

Pyrethrum powder, commonly known in the past as insect powder, is derived from the flower heads of *Chrysanthemum cinerariaefolium*, a plant native to Dalmatia and formerly grown extensively in Japan but which, since about 1939, has come largely from the cultivated crop in Kenya in eastern Africa. Large quantities are used in the control of household insects. A good product for cockroach control may contain as high as 0.7% of the toxic principles, known as pyrethrins. Insofar as can be determined, the material is entirely nonpoisonous in the food of warm-blooded animals. It has the advantage of acting rapidly and exciting insects to emerge from their hiding places; but brief exposures to its effects often result in recovery, even though the

affected insects at first appear entirely dead. The fact that the rapid action of pyrethrum and the reliability of rotenone complement each other has led to the use of mixtures of the two insecticides with better results frequently than the use of either one by itself.

Powdered insecticidal plant products are subject to deterioration upon exposure to air and light. They should be purchased as fresh as possible and only in the quantities likely to be needed, then stored in a cool place in tight metal containers. Pyrethrum is more likely to deteriorate than the rotenone insecticides. Its toxic principles are esters, and these are easily changed by moisture and heat. Neither pyrethrum nor rotenone should be mixed with any but chemically inert insecticides or carriers; alkaline materials such as powdered lime or soap solution will react to reduce their toxic value rapidly.

Much effort has been directed during the past two decades toward developing as insecticides synthetic substitutes for plant derivatives. The main object has been the production of toxicants for the fly-spray type of contact insecticide. Some, however, are being added to pyrethrum dusts to make the latter go further during the period of wartime shortages. It is probable that dichlorodiphenyltrichloroethane, commonly known as DDT, will be extensively used.

(d) *Application of Dusts*

As in the case of sprays, insecticidal dusts must be applied mechanically; but a simple garden duster of the piston type, or a bulb applicator such as pest control operators use, is generally sufficient equipment. The dust is already in an extremely fine form, whereas a sprayer must break up the liquid insecticide into fine particles as well as distribute it. The object in applying a dust is twofold: first, to pump it into any cracks that may harbor cockroaches, as behind sinks; and second, to puff it lightly and evenly in storage rooms into and through which the insects may run from nearby feeding areas. The object in the first case is to cover the hidden insects with enough dust to kill them immediately, in the second to exterminate gradually the more scattered individuals and prevent their dispersal from room to room.

3. Contact Sprays

Many of the smaller storage insects and their eggs can be killed by the application of kerosene or floor oil to cracks which cannot be completely cleaned out by sweeping or scrubbing. Gasoline should never be used for this purpose because of the explosion hazard involved. Furthermore, the heavier and less volatile oils such as kerosene will trap and kill more insects. Of course, any spray with an oil base will burn, and should be used, therefore, with due precaution against fire. Light oils evaporate fairly readily and yet have sufficient insecticidal value for application to cracks in floors, walls, and storage closets. A considerable saving will be made when such oils can be used effectively in place of pyrethrum and similar oil-base contact sprays.

When the contact spray is to be applied around raw materials or finished products, it must have a petroleum-oil base light enough to evaporate readily and refined enough

to leave no oily residue or odor. The refined oils are so low in toxicity, however, that in the small quantities used they must contain an additional toxicant to give a practical degree of kill. Although various coal-tar or phenolic derivatives are sufficiently toxic for this purpose, their odors are powerful and too easily absorbed for use around foodstuffs. The old-fashioned creosote or carbolic acid mixtures for bedbug control were representative of this type of contact insecticide.

(a) *Pyrethrum Sprays*

Excluding the water-miscible sprays intended for use on plant life, a large proportion of the contact sprays sold today is composed of pyrethrum extract distributed in a petroleum-oil base. The pyrethrum is usually a 20:1 concentrate, although 5:1, 30:1, etc., are also sold. The figures designate the dilution with oil required to obtain a spray of standard strength. The oil used is ordinary kerosene, a refined kerosene, or an odorless distillate slightly heavier than kerosene. Most of these sprays are sold for fly control where quick paralysis of the flight muscles is required to produce a visible result. Sometimes exactly the same material is sold for moth control or as a mill spray; sometimes it is modified somewhat for these purposes. The National Association of Insecticide and Disinfectant Manufacturers has adopted for sprays of this type certain grades (AA, A, and B) which can be used to guide the purchaser. The grades are determined by spraying houseflies under standard room conditions (the Peet-Grady method). It is impractical for the average consumer to prepare his own spray.

Various commercial modifications of the simple pyrethrum spray are available. Rotenone and rotenoid extractives added to a pyrethrum spray produce an insecticide from which the insects that are imperfectly exposed are less likely to recover. A number of synthetic toxicants, as *n*-butyl carbitol thiocyanate, *sec*-terpene-alcohol thiocyanyl acetate, and others, are used either to reduce the proportion of pyrethrum or to replace it entirely. Also employed are miscellaneous solubilizers to improve the transparency of the spray and reduce separation of the ingredients, perfumes to overcome inherent odors that may be undesirable, and a number of activators and extenders to increase the killing power or make possible a reduction in the content of the active ingredient.

(b) *Application of Sprays*

An oil-base contact spray should be applied with a machine that will break the insecticide into fine droplets and drive it into cracks with penetrating force. The use of a common hand-driven piston sprayer is too tiring for efficient spray application. A motor-driven sprayer sufficiently light in weight to carry in the hands is desirable. The same situations should be treated as have already been described under the headings of cockroach control and contact dusts. The advantage of the spray is its cleanliness; but after the oil has evaporated in a matter of a few hours there is no residual effectiveness. A man doing insect control work should carry a slender-tipped oil can

with which the insecticide can be squirted directly into tiny cracks where ants and other small insects are observed to hide. The sprayer should be used for general infestations and hiding places with larger openings, the oil can for liberal localized applications. A contact spray cannot be expected to do the job of a fumigant. It acts, not as a gas, but as a liquid, and must strike whatever it is to kill.

4. Insect Fumigants

An insect fumigant is an insecticide which passes into the respiratory system of the insect as a gas. See Fig. 32, page 258. It is not necessarily a gas when applied: It may be a liquid or solid from which the gas is given off spontaneously; or the gas may be produced by chemical action. A fumigant is an insecticide that penetrates and kills insects *within* a product, whereas a contact insecticide can be used to kill insects *outside* the product only. Fumigants differ in their properties and therefore in their adaptability for special situations. Relative toxicity against the insect, activity at low temperatures, penetration into compact goods, ease of application, effect upon the product, and safety to the operator are all important factors to be weighed in choosing a fumigant. See pages 95 and 96.

Temperature has a remarkable influence on results obtained by fumigation (see Table 21). At temperatures below 50° F., most storage insects become stupefied by

TABLE 21
THE INFLUENCE OF TEMPERATURE ON THE EFFECTIVENESS OF FUMIGANTS
AGAINST THE CONFUSED FLOUR BEETLE^a

Dosages in mg. per 1. to kill 100% of the insects

Five-hour exposure at temp. in ° F.	Chloropicrin	Carbon disulfide
59	12.3	140
68	9.9	108
77	7.0	91
86	5.0	68
95	2.4	40

^a Adapted from Univ. Minnesota Agr. Expt. Sta., Bull. 341, 37 (1939).

cold and are then hard to kill. The low temperature also favors absorption of gas by the materials being treated, so that high dosages are required and later the adequate ventilation of the materials takes more time. At 70°, or better, at 80°, insects are lively and more easily killed, and the gas itself becomes more active. It is not the air temperature which is most important but the temperature in the interior of the material where the insects are actually located. If possible, cold foodstuffs should be warmed before fumigation; but it should be remembered that any considerable quantity will require a long time to be heated through to the center.

In most of the larger cities local ordinances regulate fumigation, at least when hydrocyanic acid is used.

(a) Properties of Fumigants¹

Hydrogen Cyanide.—The best known insect fumigant but the most dangerous to handle is hydrocyanic acid (hydrogen cyanide or "cyanide," HCN). There are several methods of filling a room with this gas:

1. The "pot method," by the action of sulfuric acid upon sodium cyanide.
2. By the action of atmospheric moisture upon calcium cyanide dust.
3. By pumping liquid hydrocyanic acid through a piping system from outdoors.
4. By evaporation of liquid hydrocyanic acid from absorptive disks.

The gas itself has somewhat the odor of crushed peach kernels, which, however, one person in about fifteen cannot detect. The liquefied gas boils at 78° F., and its vapor has a lower density than air. Concentrations of actual hydrocyanic acid gas of 5.6% (4 lbs. per 1000 cu. ft.) and higher are inflammable. The gas is soluble in water and the solution has an acid reaction. The gas does not penetrate well into compact foodstuffs, notably flour, although this disadvantage is overcome by fumigation in a vacuum chamber. Because of the possibility of accidental overdosage which might result in dangerous quantities in food when consumed, cyanide is not used so much as formerly for the treatment of finished products. This danger, however, is negligible in foods that are to be cooked because heat drives out all the absorbed gas. Live foods such as poultry eggs, vegetables, and fruits are injured by cyanide. The gas affects the utilization of oxygen in red-blooded animals including man, a fact which explains the sudden death of exposed persons. Although its potency is well known, the layman does not often realize that the gas is absorbed directly through the skin and that, even though he wears a gas mask which gives adequate protection so far as his respiration is concerned, he cannot stay in the gas more than a few minutes at a time.

Cyanogen Chloride.—Cyanogen chloride (CNCI) has the advantage of definite warning properties, because it is one of the so-called tear gases. It is generated by the action of hydrochloric acid upon briquets containing the essential materials. The gas has an odor similar to that of hydrocyanic acid, and is somewhat soluble in water. Although it is not so well known as some of the other fumigants, it is safer to handle, appears to be more penetrating than hydrogen cyanide, and is more effective at low temperatures. It is not only highly effective as an insecticide, but also has germicidal and fungicidal properties. It has been used in the large-scale sterilization of burlap, as well as in building and boat fumigation.

Chloropicrin.—Chloropicrin (trichloronitromethane, CCl_3NO_2) is a tear gas. It was used in World War I and, from the reaction of the victim, was commonly known as "vomiting gas." The compound is a noninflammable colorless liquid, which is practically insoluble in water and boils at a temperature of 234° F., somewhat above the boiling point of water. It has a high vapor density, being practically 6 times as heavy as air. Chloropicrin can be handled as a liquid, but its low volatility and high absorption are disadvantages; long and thorough airing is required to remove the gas

¹ See Table 22, page 259.

from fumigated goods. On the other hand, because the chloropicrin clings so long, the actual exposure of insects that are buried in the goods may continue for some time after ventilation is begun. Good kills can be obtained also under such adverse conditions as the fumigation of open bins or loose structures. Although the warning character of the gas is a distinct advantage, exposure to it is so unpleasant that a less obnoxious fumigant is often chosen just for this reason. The compound is toxic to micro-organisms such as yeasts, so that flour fumigated with chloropicrin cannot be used for bread until aired for a considerable time. Involuntary weeping is produced at a concentration as low as 0.016 mg. per l. or 0.022 p. p. m., too low to have any serious physiological effect upon a person working in it; higher concentrations will drive him to fresh air before he suffers serious injury.

Methyl Bromide.—Methyl bromide (CH_3Br) is the most recent fumigant of importance. Found to have value in this connection less than a decade ago, it is already the leading gas for the chamber fumigation of foods. It is considered to have no fire hazard because its vapor can be made to burn only within very narrow limits—in fact, it has been used in fire extinguishers. It is only slightly soluble in water, but is highly soluble in oils. Being very volatile, with a boiling point of about 40° F., it must be handled under pressure in metal cylinders; its vapor density is nearly 3.5 times that of air. Methyl bromide, remarkable for its low absorption and high penetration, is the only compound known which can be used successfully in the fumigation of flour under atmospheric chamber conditions. Another notable advantage is the safety with which it can be used in the treatment of living plant materials like fresh vegetables and fruits. Disadvantages are: first, that it is rapidly dissipated in a leaky space so that most satisfactory results are obtained in a tight chamber constructed especially for fumigation; and, second, that it is practically odorless and without warning to the operator. Methyl bromide affects a person slowly without immediate symptoms so that he may not realize his danger and yet may succumb to the effects of the gas as much as two or three days later.

Ethylene Oxide.—Ethylene oxide ($\text{C}_2\text{H}_4\text{O}$), which boils at about 52° F., is another fumigant which must be handled in metal cylinders. It is soluble in water and most organic solvents. Because its vapor is inflammable the fumigant is sold commercially as a mixture of one part by weight with nine of carbon dioxide (Carboxide, Guardite) to eliminate the fire hazard. The density of ethylene oxide vapor is but little more than 1.5 times that of air. The chemical reactivity of this compound may be a disadvantage in some cases, and the gas affects the germination of seeds treated with it. The gas has a sweetish odor which is not unpleasant but at moderately dangerous concentrations it produces irritation of the eyes, a warning that further exposure will result in serious injury.

Organic Solvents.—A number of organic solvents and related compounds have insecticidal value, and are used now in a variety of fumigant mixtures. Being liquids at ordinary temperatures they do not require special equipment for storage and application. Although they are often recommended for use by the general public, they have anesthetic and toxic properties similar to those of chloroform so they should be

handled with due caution. Headache and nausea are the usual symptoms of over-dosage. None of these mixtures or their ingredients are as effective in killing insects as the fumigants described up to this point, but they find much application in localized treatments, frequently where the more toxic fumigants are too dangerous or are too easily dissipated.

Carbon Disulfide.—Carbon disulfide (CS_2) boils at 115° F. , and therefore vaporizes rapidly as compared with other organic solvents, a distinct advantage in building up a killing concentration quickly in the space to be fumigated. The vapor is almost 3 times as heavy as air. It is the most effective insecticide of all the organic solvent group. However, it is so dangerously inflammable that it should not be used by itself; in fact, under many conditions insurance is voided during such use.

Carbon Tetrachloride.—Carbon tetrachloride (CCl_4) has two disadvantages; it has a high boiling point, 169° F. , and it is of low value as an insect fumigant. It is non-inflammable, however, and for this reason is much used to remove the fire hazard of other liquid fumigants. The vapor is 5.5 times as heavy as air.

Ethylene Dichloride.—Ethylene dichloride ($\text{CH}_2\text{Cl}\cdot\text{CH}_2\text{Cl}$), found in 1927 to be a promising insect fumigant, boils at 183° F. . Its vapor density is 3.5 times that of air. Although it is much less inflammable than carbon disulfide, in effectiveness it compares favorably with that compound. Its fire hazard is removed entirely when mixed as 3 parts by volume to 1 of carbon tetrachloride (Chlorasol). It is this mixture which is commonly sold as a liquid mill or grain fumigant. The two compounds have similar vapor pressure curves and their vapors do not separate. One gallon of the mixture weighs 11.2 pounds at 68° F. .

Propylene Dichloride.—Propylene dichloride ($\text{CH}_2\text{Cl}\cdot\text{CHCl}\cdot\text{CH}_3$) has about the same toxicity and other properties as ethylene dichloride, but its boiling point is higher (205° F.) and the compound does not vaporize as readily. It has been used to some extent as a substitute for ethylene dichloride.

Trichloroethylene.—Trichloroethylene ($\text{CHCl}\cdot\text{CCl}_2$) is not inflammable, so it is a potential substitute for carbon tetrachloride. An advantage over the latter compound is its slightly higher toxicity; but this may be offset by lower vapor pressure, trichloroethylene boiling at 189° F. It has been used relatively little in fumigant mixtures.

Methyl and Ethyl Formates.—Methyl and ethyl formates are sometimes encountered in fumigants. The first boils at 89° F. and has been available commercially in combination with carbon dioxide in pressure cylinders. The second boils at 130° F. , so it is easily handled as a liquid. It is somewhat more effective even than carbon disulfide; but its use appears to be limited to the fumigation of dried fruit during the packaging process, although the method may easily be applicable elsewhere.

Fumigant Mixtures.—Besides the noninflammable 3:1 mixture of ethylene dichloride and carbon tetrachloride, some other combinations having similar effectiveness and utility are commercially available. Small amounts of carbon disulfide are sometimes added to the 3:1 mixture to enhance its effectiveness. Another mixture frequently used in stored grain fumigation contains 80% carbon tetrachloride and 20% carbon

disulfide, often with enough sulfur dioxide to increase the toxicity slightly and act as a warning agent. In an effort to save chlorinated hydrocarbons for other industrial purposes, a mixture has recently been used extensively that contains 10% by weight of

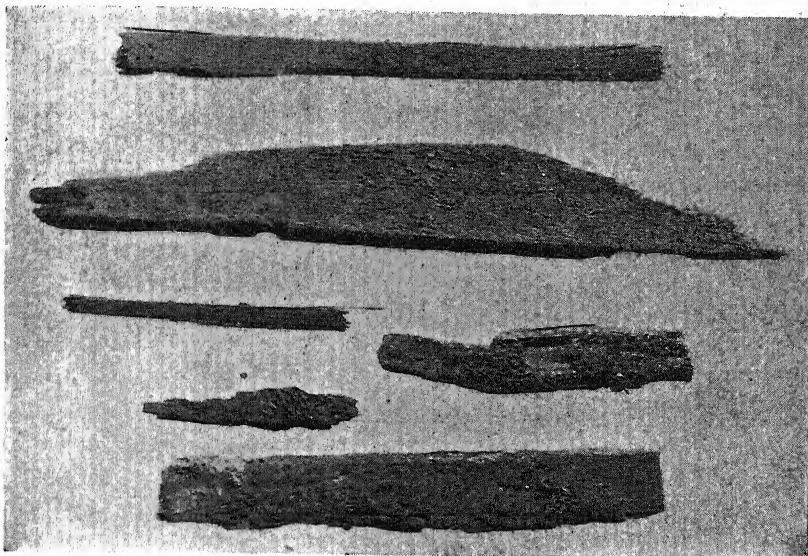


Fig. 29.—Wooden debris bearing spider beetle holes and cocoons, collected under the floor of a storage warehouse (see page 244). (From Minn. Agr. Expt. Sta., *Bull.* 341 (1939).)



Fig. 30.—Indian-meal moth resting on wall and showing characteristic whitish band across the reddish brown wings (see page 246). (Enlarged $\times 2$.) (From Illinois Agr. Extension *Circ.* 512 (1941).)



Fig. 31.—Larva or feeding stage of Indian-meal moth (see page 246). (Enlarged $\times 2$.) (From Illinois Agr. Extension *Circ.* 512 (1941).)

methyl bromide absorbed in the 3:1 ethylene dichloride fumigant. The methyl bromide increases the effectiveness of the original mixture enough to reduce the required dosage for grain bin treatment to only one-half that of the 3:1 mixture by itself.

Only mixtures put up by reputable manufacturers and sanctioned by the fire insurance underwriters should be considered. Since individual trade preparations vary in their formulas, it is wise to follow the directions of the manufacturer in their use.

Sulfur Dioxide.—Although sulfur dioxide (SO_2), produced by burning sulfur, is a highly effective fumigant nearly as toxic to insects as chloropicrin, it is so active chemically and in water produces such a strong acid that its use is limited to the disinfestation of empty buildings in which no food products will be exposed to the fumes. The gas is slightly more than twice as heavy as air.

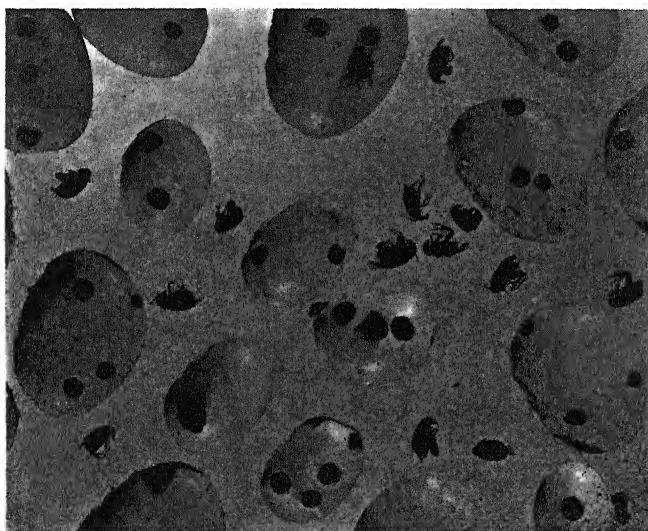


Fig. 32.—Common bean weevil, and beans showing their emergence holes. (Enlarged $\times 2$.) (From Minn. Agr. Expt. Sta., Bull. 340 (1939).)

Questions are frequently asked as to the use of either formaldehyde or carbon monoxide in the control of insects by fumigation. Formaldehyde is not a practical insect fumigant, although it can be effectively used against various fungi and bacteria. Carbon monoxide, well known to be very toxic to human beings, owes its potency to its selective affinity for the hemoglobin of red blood. Since insects do not possess this kind of blood they are not affected by the gas to any greater extent than by any other inert gas such as nitrogen.

(b) Building Fumigation

The general fumigation of entire buildings is seldom necessary if an adequate cleaning routine is practiced, although under some conditions, as in flour mills, it is advisable to fumigate throughout the plant once or twice a year. If a general fumigation does become necessary it should be undertaken only by persons experienced in this

dangerous work. There are now professional fumigators in all the larger towns who can be called in, and who not only have the experience but the necessary insurance, licenses, equipment, and supplies. The food technologist seldom needs detailed information as to the methods of general fumigation; when he does it can sometimes be

TABLE 22
PROPERTIES OF INSECT FUMIGANTS

Compound	Mol. wt.	B. p., °C.	Vapor pressure at 25° C., mm. Hg	Wt. of U. S. gal. at 20° C., lbs.	Explosive limits of vapor % by vol.	
					Lower	Upper
Sulfur dioxide	64	-10	760	...	Noninflammable	
Methyl bromide	95	5	760	...	13.5	14.5
Ethylene oxide	44	11	760	...	3	80
Cyanogen chloride	61	14	760	...	Noninflammable	
Hydrocyanic acid	27	26	739	...	5.6	40
Carbon disulfide	76	46	361	10.5	1.0	50
Ethyl formate	74	54	...	7.7	3.5	16.5
Carbon tetrachloride	154	76	114	13.29	Noninflammable	
Ethylene dichloride	99	84	80	10.45	6.2	15.9
Trichloroethylene	131	87	73	12.2	Noninflammable	
Propylene dichloride	113	96	...	9.64	3.4	14.5
Chloropicrin	164	112	24	13.75	Noninflammable	
p-Dichlorobenzene	147	172	1	...	..	..
Water (for comparison)	18	100	24	8.33	Noninflammable	
Gasoline (for comparison)	...	...	...	...	1.3	6

obtained from the manufacturer of the fumigant in which he is interested. Hydrocyanic acid is the gas most used for the treatment of whole buildings, although chloropicrin is also frequently employed and is especially valuable for structures of loose construction. Methyl bromide is most effective only where the construction is very tight, but in such locations penetrates foodstuffs better than do other gases.

(c) Chamber Fumigation

Where second-hand sacks and rejected shipments are commonly received, a fumigation vault or chamber should be constructed in which to rid these materials of insects; otherwise they will be a continual source of plant infestation. A room lined with sheet metal and equipped with refrigerator-type doors fitting against rubber gaskets forms a safe, gastight chamber. It should be arranged with heating coils and a fan that will circulate the gas during fumigation and exhaust it outdoors afterward. The piping connections for introducing measured quantities of fumigant differ according to the gas to be used. Advice concerning them should be obtained from the manufacturer of the fumigant. Methyl bromide is well adapted to chamber fumigation and can be piped in from outside. Liquid fumigant mixtures containing ethylene dichloride and carbon tetrachloride may be employed; but a motor-driven sprayer will be required unless the fumigant is sprinkled over the load by hand before the vault door is closed.

If a sprayer is used, it should deliver the fumigant in a coarse spray in order to distribute the entire charge within as short a time as is practical. Exposure in a pan at the top of the chamber is a frequent practice, but volatilization is much slower and the method has little to recommend it. Chloropicrin is a safe fumigant from the standpoint of warning; but it cannot be aired out rapidly and it must be sprayed into the chamber. If diluted 50:50 with carbon tetrachloride it can be distributed more efficiently. The load to be treated should be arranged for good gas circulation with spaces between the stacks and the latter raised on racks. Certain materials absorb excessive amounts of some gases and require longer ventilation before they can be handled, as, for instance, nuts gassed with hydrocyanic acid. Based on a load of 15 tons of bagged grain in a vault at 80° F., exposed for 24 hrs., the dosage per 1000 cu. ft. of methyl bromide is 1 lb., of chloropicrin—3 lbs., and 3:1 ethylene dichloride mixture—30 lbs. For bagged flour or feed the dosage must be nearly 3 times as much. Methyl bromide is the only fumigant of the three which will penetrate flour readily.

It is frequently necessary to fumigate loaded railroad cars. To insure penetration of fine, compact materials such as flour, 10 lbs. of methyl bromide can be introduced through a copper tube in the bottom of the sealed car and allowed to remain at least 12 hrs. The car should be made thoroughly tight with masking tape because the methyl bromide is likely to be lost through small cracks around the door. Box cars in which food products are to be shipped should be cleaned thoroughly with compressed air. The products themselves, before being loaded, should be inspected if they have been in storage and subject to contamination from infested buildings or products.

(d) Vacuum Fumigation

Vacuum fumigation is adapted to the treatment of packaged foods and solidly baled materials that are relatively impervious to the gas under atmospheric conditions. The goods are loaded into a gastight steel chamber, most of the air pumped out, and the fumigant introduced through a valve. Vacuum fumigation is a rapid process recommended where goods must be kept moving rapidly. Hydrocyanic acid, chloropicrin, methyl bromide, and ethylene oxide-carbon dioxide mixture are commonly used in this process. As in atmospheric chamber fumigation, it is sometimes necessary to have special equipment at the point of introduction for warming an expanding gaseous fumigant or for vaporizing higher boiling liquid fumigants.

(e) Spot Fumigation

The so-called spot fumigation of infested bins or machinery is sometimes practicable with 3:1 ethylene dichloride mixture. The fumigant is poured evenly over the contents of a bin or squirted into a machine, the quantity depending upon the tightness of construction and the amount of absorbent material present, varying from 14 to 30 lbs. per 1000 cu. ft. It is necessary either to provide ample ventilation of rooms in which workmen might be exposed to fumes or to lock up and post warnings against entering.

Office samples of seeds, etc., can be protected against cabinet beetles (see Fig. 33), grain weevils, and Indian-meal moths (see Figs. 30 and 31, page 257) by adding a few crystals of *p*-dichlorobenzene, which is sold commonly for protecting clothes from moth damage.



Fig. 33.—Cabinet beetles and their larvae with injured corn kernels.
(Enlarged X4.) (From Minn. Agr. Expt. Sta., *Bull.* 340 (1939).)

(f) Safety Precautions

If any of the more dangerous fumigants, such as hydrocyanic acid, chloropicrin, ethylene oxide, or methyl bromide, is to be used, gas masks should be available and worn whenever there is danger of exposure. When the fumigator is liable to more or less continuous exposure to the less toxic fumigants such as ethylene dichloride mixture, a gas mask should be worn then also. It is important to remember that no insect fumigant has been found that is free from human hazard. The liquid fumigants such as carbon disulfide, ethylene dichloride, and carbon tetrachloride have an anesthetic effect and soon produce headache and drowsiness. One gas mask cannot be used for all gases; it must be fitted with a canister made especially to absorb a specific type of gas, and this canister must be changed for a new one according to directions of the gas mask manufacturer. Even though a person has full respiratory protection, hydrocyanic acid, as stated previously, will overcome him within a short time by absorption through the skin. It has been stated that a fumigator walking away from the higher concentrations during his work may be exposed to 1 or 2 oz. per 1000 cu. ft., and that this amount can be tolerated for about half an hour if he is protected by a mask in good working order. If a person wearing a mask must enter a space in which the full load of 8 oz. of hydrocyanic acid per 1000 cu. ft. (equivalent to about 1 lb. of sodium cyanide per 1000 cu. ft. or 0.65% of actual hydrocyanic acid in the air) is distributed throughout, he cannot stay over 5 min. For comparison it can be stated

that the concentration dangerous to breathe for 30 min. to an hour is as low as 0.15 oz. per 1000 cu. ft. In acute poisoning from breathing strong cyanide fumes, a person falls unconscious after only a breath or two of the contaminated air. On every fumigation vault there should be posted a chart of first-aid instructions for handy reference. Workmen should not be allowed to gain the impression that dust masks give any protection whatsoever against poisonous gases. A workman should never be sent into an unventilated grain bin or any other space where the oxygen of the atmosphere has possibly been replaced by carbon dioxide, unless he is secured to a rope by which he can be hauled out in case he is overcome. A gas mask for counteracting oxygen deficiency of the air must be equipped with either an oxygen tank or a pump for supplying fresh air through a hose from outside. The usual mask for protection against fumigants is not so equipped. Freshly fumigated merchandise should be stored in a well-ventilated room, especially if it is necessary for anyone to work in the vicinity.

5. Heat Treatment and Cold Storage

High temperature limits the development and existence of insects more completely than the layman often realizes. For instance, the confused flour beetle at 90° F. is able to complete its growth from egg to mature beetle in as short a time as 27 days.

TABLE 23
THE EFFECT OF TEMPERATURE ON THE CONFUSED FLOUR BEETLE^a

Temp., ° F.	Summary of data from various sources
0.....	Average time to kill adults, 9 minutes
10.....	Average time to kill adults, 14 minutes
21.....	Average time to kill adults, 8.4 hours
45.....	Average time to kill adults, 14 days; maximum, 22 days
54.....	No eggs laid
63.....	Eggs are laid and hatch, but larvae die before completing development
72.....	Life cycle completed in 93 days
81.....	Life cycle completed in 37 days
90.....	Life cycle completed in 27 days
100.....	Life cycle completed in about 38 to 40 days; egg viability reduced about 25%
106.....	Larvae unable to complete development
111.....	Average time to kill adults, 7.5 hours; maximum, 14.5
115.....	Average time to kill adults, 66 minutes
118.....	Average time to kill adults, 26.5 minutes
122.....	Average time to kill adults, 7 minutes

^a From Univ. Minnesota Agr. Expt. Sta., *Bull. 341*, 12 (1939).

This temperature appears to be close to the optimum for development, since both at the lower temperature of 81° and at the higher one of 100° the life cycle of this insect requires from 37 to 40 days (see Table 23). At 100° not only is the rate of development reduced, but egg viability is diminished by 25%. At 111°, the beetles are killed in an average of less than 8 hrs., at 122° in 7 min. Moderate heat, then, is an excellent means of killing insects except when the infested material will be dried out too much or if sufficient time cannot be spared to heat the products through. It is adapted to the

disinfestation of second-hand bags but seldom of flour in sacks. When a product is heated as part of a continuous process, as in the manufacture of breakfast cereals or dehydrated foods, packaging it in an insect-resistant container while still hot is excellent insurance against infestation prior to its ultimate consumption. The temperatures advised for disinfection usually range from 120 to 140° with the exposure long enough to insure heating throughout. It is impossible to say beforehand just how efficient a given temperature chamber will be with respect to heating time, but a few tests will provide the necessary data. The chamber for this purpose should be tight and well insulated, with opportunity for circulation of the heated air not only over and around the material but under it as well. A chamber can easily be fitted for either fumigation or superheating of merchandise.

TABLE 24

TIME IN HOURS REQUIRED TO KILL GRAIN WEEVILS AT VARIOUS LOW TEMPERATURES*

Temp., ° F.	Granary weevil (<i>Sitophilus granarius</i>)	Rice weevil (<i>Sitophilus oryzae</i>)
45	..	350
35	875	160
30	545	98
20	100	14
10	70	3.5
0	2.5	1.5

* From Univ. Minnesota Agr. Expt. Sta., *Bull. 340*, 24 (1939).

Low temperatures, even above freezing, will kill many stored food pests in a short time. Unfortunately a few insects, mostly less common species, are fairly resistant to cold, so this means of disinfection is not always practical. As an example of a common species easily killed by chilling, the confused flour beetle (see Figs. 34-36, page 264) dies in 15 to 20 days at a temperature as moderately low as 43° F. At 0°, it is killed in a few minutes (see Table 24).

III. FUNGICIDES AND MOLD INHIBITORS

Fungi, as in the case of insects, may be either harmful or beneficial. They may be relatively simple forms as represented by the yeasts, or possess a complicated life cycle as in numerous species affecting plant life. Forms important to the food technologist are molds, largely species of *Aspergillus* and *Penicillium*. Various *Penicillium* species, or "blue molds," are common contaminants of uncooked cereals, bread, fruits, etc., and specific ones are used in the ripening of certain cheeses. Fungicides to control molds during the processing and storage of foods fall under several headings: washes and sprays for decontamination of premises; fungicidal paints; container treatment; and product treatment.

Molds can be controlled considerably by washing walls and shelves with 10% copper sulfate or 5% borax solution. Other chemical agents useful for this purpose

are formaldehyde (up to 4% formalin), mercuric chloride (0.2%), sodium hypochlorite, and other disinfectants and antiseptics. The control of air-borne mold spores by an aerosol composed of resorcinol and glycerol has shown some promise.

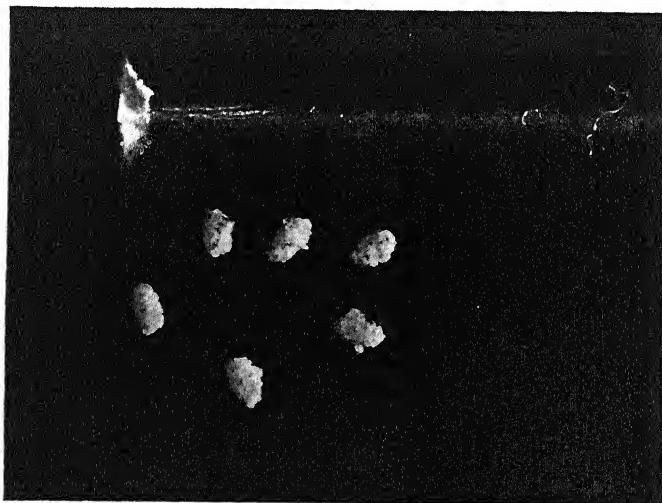


Fig. 34.—Eggs of confused flour beetle, with head of a common pin for comparison. (Enlarged $\times 10\frac{1}{2}$.) (From Minn. Agr. Expt. Sta., Bull. 341 (1939).)



Fig. 35.—Confused flour beetle, a common pest of cereals and other dry food products. (Enlarged $\times 6$.) (From Minn. Agr. Expt. Sta., Bull. 341 (1939).)

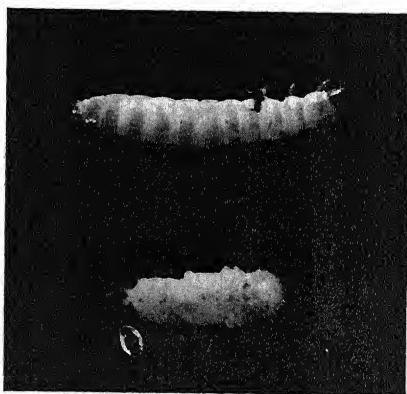


Fig. 36.—Larva or feeding stage, and pupa or resting stage, of confused flour beetle. (Enlarged $\times 6$.) (From Minn. Agr. Expt. Sta., Bull. 341 (1939).)

Molds develop in paint on surfaces which are exposed to high humidity, also on warm concrete walls subject to moisture seepage. These growths can become rich sources of

product contamination. Outside paints high in zinc oxide are much less likely to mildew than white lead paint.² Under certain conditions in breweries, the base surface should be treated with mercuric chloride or thymol. Some paints have an antiseptic added, such as chlorophenols and hydroxyquinoline sulfate, but in the most effective fungicidal paints the linseed oil is chlorinated to contain 4% halogen.³ "Spores of *Aspergillus* and *Penicillium* molds suspended in water solutions of flour and dextrose failed to develop on halogenated painted glass surfaces tested 104 days after application."

In the past, boxes have been dipped in borax before waxing as a prevention for mold contamination during shipping and storage. However, this would need to be done in such a manner that the food product does not take up the borax.

It has been found that flats and fillers in egg cases impregnated with chemicals of relatively high vapor pressure, such as 0.4% sodium pentachlorophenate, will protect from molding eggs that are stored for 3 to 6 months in such packing materials. This method can be applied to other products likely to mold during storage.

In recent years, mold inhibitors have been developed to take advantage of the fungistatic powers of the fatty acids and their salts. These are now being used in controlling mold development in bread, cheese, and butter. The mold-free life of bread is extended by 7 or 8 days with the addition of 2.5 to 5 oz. of propionates per 100 lbs. of flour. Not only propionic acid and its calcium and sodium salts but also sodium diacetate are employed successfully in bread. Tests with cheese showed that propionic acid in 8% solution, used for dipping rather than swabbing over the cheese, remained free of visible mold twice as long as the check. Calcium propionate has less inhibitory action than the acid. It is said, however, that a mixture of 10% of the calcium salt and 10% of the acid in the ratio of 5:1 provides an immersing agent with a pH of about 5 and with a superior inhibitory action upon molds common on cheeses. The most effective method of keeping down surface mold on cold-packed cream cheese is to treat the wrappers with a wax containing propionic acid. Butter wrappers containing either 6% calcium propionate or 12% sodium propionate greatly inhibit the growth of mold, especially when they are wetted before wrapping. The pH of the medium influences the effectiveness of a treatment. The various species of molds vary decidedly in their susceptibility to the treatment.

IV. CONVERSION FACTORS

One cubic foot = 7.481 gallons (U. S.) = 0.804 bushel (U. S.) = 28.316 liters.

One liter = 0.264 gallon (U. S.) = 0.220 gallon (Brit.).

One gallon (U. S.) = 0.134 cubic foot = 3.785 liters.

One gallon (U. S.) of water at 15° C. (62° F.) weighs 3.782 kilograms or 8.337 pounds.

One gallon (Brit. or Imperial) = 1.20 gallons (U. S.) = 0.161 cubic foot = 4.546 liters.

One gallon (Brit.) of water at 15° C. (62° F.) weighs 4.536 kilograms or 10 pounds.

² A. M. Partansky and R. R. McPherson, *Ind. Eng. Chem., Anal. Ed.*, 12, 443 (1940).

³ S. S. Epstein and F. D. Snell, *Ind. Eng. Chem.*, 33, 398 (1941).

One bushel (U. S.) = 1.2444 cubic feet = 35.238 liters.

One bushel (Brit.) = 1.2843 cubic feet = 36.368 liters.

One ounce (avoird.) = 28.35 grams.

One pound (avoird.) = 453.59 grams.

One pound per 1000 cubic feet = 16.02 milligrams per liter.

One pound per 1000 bushels (U. S.) = 19.94 milligrams per liter.

One milligram per liter (atmospheric) = $\frac{22.4 \times 100}{\text{mol. wt.} \times 1000}$ volume per cent.

One part per million (atmospheric) = 0.0001 volume per cent.

X degrees Fahrenheit = $\frac{5(X - 32)}{9}$ degrees Centigrade.

X degrees Centigrade = $\frac{9X}{5} + 32$ degrees Fahrenheit.

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Chapter VIII

THE PREVENTION AND CONTROL OF RODENT LIFE

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Rodent control and the prevention of the incidence of rat life in building structures used as plants for the manufacture, processing, and storage of food products, through the medium of ratproof construction and installations, are most important considerations in safeguarding food from pollution. This chapter will discuss the measures that should be taken to protect and safeguard food products from pollution and contamination because of the presence of, or contact with, foreign bodies and putrefactive agents, especially the body filth and excretions of rodents.

I. DISEASE AND CONTAMINATION

In addition to the agents of contamination described in preceding chapters, there is another which is a potential source of contamination of food products. This agent is none other than the rat, which, during its nightly migrations in search of food, drink, companionship, and romance, destroys or renders unfit for human consumption many articles of food, through contact therewith and by polluting them with its body filth and excretions.

In the past, the presence of the rat has very generally been ignored. As a consequence, but little of a constructive character has been done to control its activities or to prevent the possibility or risk of such contamination or destruction. No consideration was given, by the great majority of persons, to the fact that rodents, especially rats, disseminate certain diseases, as well as render numerous articles of food unfit for human consumption as a result of actual contact.

Weil's disease may be spread by intimate contact with raw food materials polluted with the urine of rats. Rodent excreta when deposited on the surface of prepared foods contaminates it, and frequently results in outbreaks of food poisoning of specific types. Mice especially are very active in this respect, their excreta being much smaller than that of the rat and as a consequence not so easily discovered. To a certain extent rats play a role in the transmission of trichinosis, the result of the close contact and association made possible through the establishments of homes by rats in piggeries and pigsties.

Surveys have revealed the fact that rats frequently gnaw into the carcasses of slaughtered animals and dressed poultry being held in cold storage, and mutilate and pollute them so badly that the meats and fowl have to be condemned and destroyed.

It has been discovered further that infected rats living in food markets, cold storage plants, flour and grain mills, grocery stores, and other establishments where food products are stored or distributed frequently are the agents contributing to the spread of endemic typhus fever.

Because insanitary conditions, as a result of the presence of rodents or rodent infestation, have been found to exist in food processing and distributing establishments in many sections of the country, cognizance was taken of the fact that these conditions constitute a danger to health when the Federal Food, Drug and Cosmetic Act was drafted by Congress in 1938.¹ The act contained a provision in Section 402 which was intended to cover such conditions. It read as follows: "A food shall be deemed to be adulterated (3) if it consists in whole or in part of any filthy, putrid or decomposed substance, or if it is otherwise unfit for food; or (4) if it has been prepared, packed or held under insanitary conditions whereby it may have been contaminated with filth, or whereby it may have been rendered injurious to health."

Rodent excretions, body hairs, and filth are agents and sources of food contamination; and contact with such material will render food products injurious to health. Therefore, if it is found that food products have been adulterated, contaminated, or rendered injurious to public health, the permit of the manufacturer, processor, or packer to engage in interstate commerce may be suspended, pending the taking of adequate measures to comply with and maintain the conditions of the permit as originally issued. Since the enactment of this law, persons engaged in the processing of foods, in public health activities, and in the enforcement of food and drug laws and regulations have been compelled to realize the fact that there is an actual and urgent need for the employment of effective measures to eliminate rodent life permanently from buildings used by operating companies and individuals engaged in the manufacture, packing, storage, and distribution of foods and drugs.

The recognition of the need for the elimination of rodent life presupposes, of course, its existence in the majority of buildings in which such industries are conducted. The findings of many carefully conducted surveys have revealed the fact that this assumption is well founded, and that a real necessity does exist for the prevention of the incidence of rat life in food industry plants, in order to reduce the opportunity, risk, and the possibility of contamination and pollution of food products by rodents.

Recently, stress has been laid on the adulteration of foods brought in contact with strands of hair brushed from the fur on the body of the rat during its passage over the surface of materials stored in food bins and other containers. Many instances of such contamination and pollution, especially in bakeries and candy manufacturing plants, have been reported from various sections of the country.

¹ *Federal Food, Drug and Cosmetic Act*, approved June 25, 1938.

II. MEASURES OF ERADICATION

It is now generally realized that, if the conditions which are principally responsible for providing ways, means, and the opportunity for rodent contamination and pollution are to be eliminated and permanently maintained, measures of a definite, constructive character will have to be adopted and incorporated in the planning, operating, and upkeep program of food products establishments.

It would appear to be pertinent at this point to inquire, "What are such measures?" "In a practical way, how may they be applied?" "What changes and corrections will it be necessary to make?" These questions are proper and logical, and will naturally be asked by the thoughtful executive or operator. The rodent problem is one that has been an ever-present source of annoyance and worry to plant operators, even though they may not have considered the menace to health which the presence of rats involved. The one thing well known to most owners and operators is that rodent infestation of many buildings has been the normal condition for centuries, and that it has been tolerated for the same period of time. It will be recalled by them, also, that whenever the rodent problem had become acute and unbearable, because of the destruction or pollution of merchandise by rats or mice, reliance for relief had been placed always on the employment of measures which had as their objective the destruction or killing off of the pests, rather than measures making it impossible for rodents to be in the building at all, as by depriving them of the facilities they need to establish homes, build nests, and bring up families within the enclosed spaces of the structure of the building and its fixtures and equipment.



Fig. 37.—Typical rat hole in base board and plastered wall.

1. Killing

Many means have been employed to exterminate rodents; the most common ones being poisoning, trapping, fumigating with poisonous gases, and employing animals known to be natural enemies of the rat. While some satisfactory results, of a temporary character, have followed the use of these supplementary and auxiliary measures, the consensus of opinion among the best-informed scientists and public health officials in many countries of the world is that these measures have failed to attain the desired objective, in that satisfactory permanent rodent control and the prevention of the presence of rat life in building structures was not obtained. These results have demonstrated, also, that much remains to be accomplished if the problem is to be

solved, if the mistakes which have been made in the past are to be avoided, if a constructive program based on scientific principles is to be adopted, and if approved standard methods for carrying it out are to be employed.

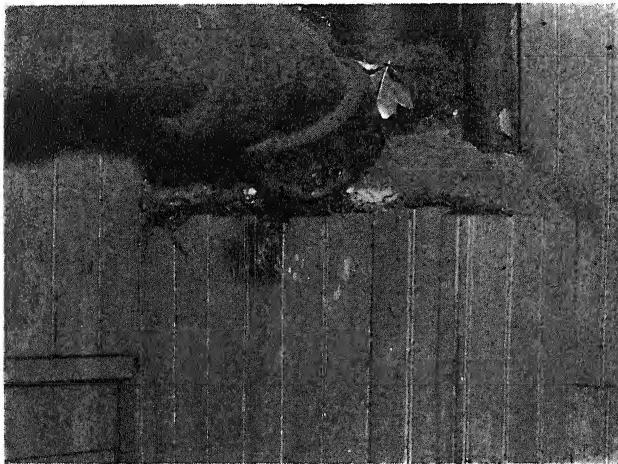


Fig. 38.—Rat home in pipe casing and entrance to same.

2. Permanent Control

It is permanent rodent control and prevention of the presence of rat life, rather than periodic reduction in numbers or the temporary eradication of these destructive agents, that will confer the highest degree of protection and reduce the risk of pollution and contamination of food products. The old proverb, "An ounce of prevention is worth a pound of cure," applies with telling force in matters pertaining to the solution of this world-wide problem.

Failure to give serious consideration to the potential as well as the present risks and menaces which follow as a result of the continued presence of permanent colonies of rats in building structures, to understand the fundamental conditions that are responsible for and make possible rodent life, or to obtain and use information relating to the habits, etc., of rodents, may be cited as some of the causes for the lack of success so commonly experienced by so many interested persons.

The first step to be taken in the solution of the problem is to become intimately acquainted with all the factors involved, and to understand the relation each one bears to the other and the fundamental role that each one plays in the perpetuation of rat life.

The first factor, of course, is the rat. A knowledge of its habits is essential to an intelligent effort to prevent its presence, the establishment of its nests, and its propagation.

The second factor is the public, the victim and sufferer from the rat's depredations. It is the public which provides the rat with all the necessities of life in the form of a home or nesting place and of food. No satisfactory sanitary results of a permanent



Fig. 39.—Rat homes under raised wooden floors.

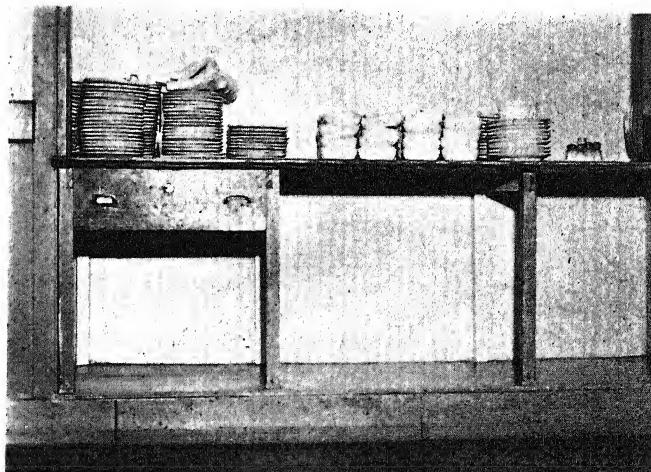


Fig. 40.—Example of corrective ratproofing applied to fixtures.

nature may be expected until people become "rat minded," conscious of the fact that the rat, through their carelessness and inattention, is being supplied with all its biological necessities.

The third factor in this problem of rodent control and prevention, is constituted authority, in the form of State, municipal, and county governments. These agencies can render very valuable aid by providing for the education of the public on this subject, through the medium of lectures and demonstrations, and by imparting first-hand

information to owners and occupants of buildings, as well as to architects, builders, and others engaged in the construction and repair of buildings. Codes, regulations, and specifications that are vitally needed to guide the owners and others have to be promulgated by the administrative representatives of such local governments.



Fig. 41.—Ratproof construction of ceiling in food plant.

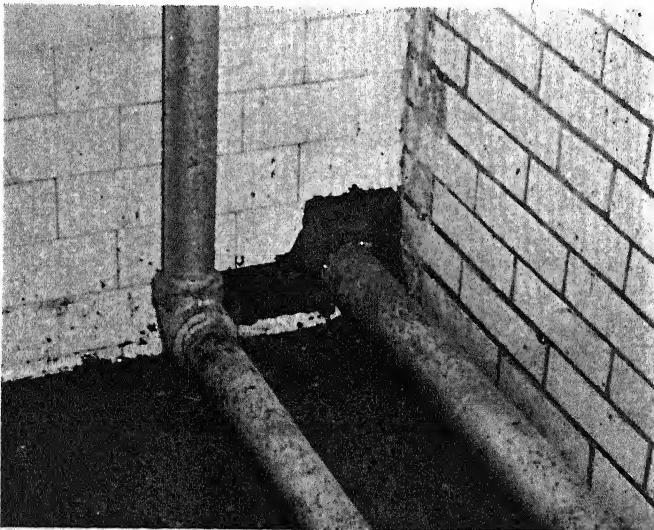


Fig. 42.—Openings in double walls closed with cement plaster.

The fourth factor, and one of the most important, in this problem of rodent control is technical aid. Without it, the efforts of persons who are genuinely interested in and desirous of rodent control will be more or less wasted. It is not only desirable

but absolutely necessary that such persons provide themselves with a well-devised technical plan, and that they follow the instructions given in the specification.

It will be seen that each of the four factors mentioned above plays an important role in solving the rodent control problem. None of them can be ignored or disregarded without seriously interfering with the success of the undertaking. Many persons having a rat or other rodent problem on their hands fail to understand this, with the result that another failure is recorded or that their problem is but partially solved.

III. RAT HARBORAGES

The natural home of the species of rat, *Rattus norvegicus*, that most commonly infests building structures in this country is in burrows which it tunnels in the earth. The average depth of the burrows is about 20 inches. This information may be used to advantage when plans are being drafted to "build out" the rat and to prevent him from invading buildings and establishing homes.

This species, known commonly as the brown rat or sewer rat, and sometimes as the wharf rat, prefers to establish a home in a burrowlike enclosure in the earth and, if given the opportunity, beneath concrete or stone slabs, wooden pavements, or other types of sidewalks. Since such housing facilities very often are not available, this resourceful creature gracefully accepts the situation and readily adapts himself to the environment in which it finds itself, selecting a nesting place in one of the dozens of enclosed spaces which man, in his thoughtless moments, has so generously provided for rodent use. Here not only has the housing facility, rat harborage, been provided, but also a suitable and convenient means for ingress and egress.

Conditions which furnish the rat with housing facilities and which are basically non-ratproof, are found very frequently in the enclosed spaces between double or hollow walls (see Fig. 37, page 269), between floors and ceilings, in the pockets of hollow tile walls, in the insulated spaces of refrigerating and cold storage units, in housing or pipe casings (see Fig. 38, page 270), installed around heater pipes and radiators, and beneath basement and cellar floors, whether they are of wooden, brick, or concrete construction. Housing facilities also are to be found in many types of equipment installed in industrial and food processing and storage plants, especially in bins, boxed-in shelving units, lockers, and other storage units. Since no constructive measures have been taken to eliminate these harborages, rodent life has become securely entrenched in such places and permanently established therein.

In many instances, nests containing litters of young rats or mice, excreta, scraps of food, etc., have been discovered in bottom drawers and bases of desks, in wooden filing cases, in double bottoms of storage bins, in hollow bases of shelving units, in serving counters, in locker units, and beneath raised platforms and many types of floor gratings. See Fig. 39, page 271. It has been found that rodents have built nests in the hollow bases of electric motors and in those of mechanical refrigerating units. The discovery of rat homes and nests in the insulating material installed between the walls of large refrigerating storage plants is of common occurrence. Rodents gain

access to these double-walled insulated spaces through openings around pipe and cable lines passing through the walls and which have not been properly closed and protected against rat invasion, through open spaces beneath poorly fitted doors, and through holes which rodents gnaw themselves when an accidental means of ingress, as has been described, is not available. The places that are generally selected by rodents for carrying out their gnawing operations are located in the dark, out-of-the-way spots, where they will not be seen or easily discovered. The practice of cutting holes in partition walls, floors, and enclosed ceilings of building structures to permit pipe and cable lines to be installed and extended from compartment to compartment, and from floor to floor, and then leaving such openings unclosed and unprotected, has provided the rat with both the means and the opportunity for gaining access to the several sections and floors and to expand its field of operations.

Facilities like these exist in the structure of a great many buildings in which plants for the manufacture and storage of foods are installed. Practically all the older type of buildings contain a great number of structural rat harborages; and many such buildings have been rat infested for long periods of time.

In a word, the rat has been given "the key to the city," has been provided with a well-equipped home, and furnished with every facility for carrying on the normal functions of rodent life, the propagation of its species. It is no wonder, therefore, that the rat has become so securely entrenched in building structures, and has been able to resist successfully the efforts which have been made to dislodge it therefrom, or permanently to prevent its further invasion and occupancy.

As stated previously, this condition of affairs has been made possible because of man's inertia, his lack of understanding of the fundamental factors involved in this problem, and further, because serious consideration has not been given to the matter of utilizing the ways and means, which have been provided and are available, of eliminating the fundamental causative factors. On the contrary, reliance continues, in many instances, to be placed on the use of temporary expedients.

IV. RATPROOFING

1. Definition and Objectives

It has been found that, if the principles of ratproof design and construction are incorporated in plans and specifications for the erection of buildings and for the units of equipment and fixtures that are to be installed therein, the conditions which favor the permanent presence of rat life in building structures and which provide the rat with a home can be eliminated, and its incidence prevented. The method recommended to obtain this objective is called "ratproofing."

What is ratproofing? Technically it may be defined as the process of preventing rats, by mechanical means, from gaining access to and using enclosed spaces within the structure of the building itself, its fixtures, and equipment, for the purpose of establishing homes and bringing up families. Its purpose also is to deprive rodents of the opportunity to obtain access to food, and thereby prevent damage to and pollution

of all kinds of food products, raw, as well as those which have been processed. Biologically, ratproofing has for its prime objective the prevention of reproduction of the rodent species, employing a procedure that is the very opposite to that which has been so successfully used in preventing a useful and desirable species from becoming extinct. This latter procedure, which has been designated as game preservation, has accomplished its purpose by providing a housing facility or sanctuary that is as nearly identical with the natural habitat of the animal or species threatened with extinction as is possible to obtain, thus enabling it to shelter and protect its helpless young until maturity. In ratproofing, the procedure is reversed. Every effort is made, first, not to provide rodents with such housing facilities, and second, to deprive them of every opportunity to establish permanent homes or to bring up families.

The ratproofing of buildings, fixtures, and equipment is a two-sided undertaking. It involves the elimination or correction of conditions that provide rodent housing facilities, as well as the planning for the incorporation of basic ratproof designs and installations in new constructions. See Figs. 40, 41, and 42, pages 271 and 272.

In order to be prepared to carry out ratproofing in an efficient manner, one should understand and be able to recognize conditions that are basically nonratproof and that provide rat harborage. Such a preparation will enable one to avoid many mistakes that have been made in the past, and to incorporate adequate provisions for ratproof constructions. It seems pertinent to state once again that rats exist in our buildings because we provide them with enclosed spaces for homes; if we desire to prevent rodent infestation we must eliminate enclosed spaces as far as it is possible to do so. A rodent cannot occupy a space or enclosure that does not exist. Neither can it invade an enclosed space between double walls or beneath floors that have been protected by the installation of ratproof material impervious to rat gnawing.

2. Current Practice vs. Ratproofing

Unfortunately, the solution of the rodent problem has been, and continues to be, approached from an unscientific angle, to say the least. Efforts to solve it have been based on principles that fail to consider the scientific factors involved, the biological factor being completely ignored.

Dr. M. T. Morgan, Medical Officer of Health, Port of London, England, a distinguished British scientist, recently described the general situation in these words: "Much of the so-called 'folk lore' about the habits and customs of rats has its origin in ignorance and superstition, and further . . . the methods used have hardly varied from those employed centuries ago, which consist of haphazard baiting and trapping . . ." "What is needed is an entirely new conception of the importance and scientific status of this activity. This can only be brought about by scientifically training [personnel] in the habits and customs of each species of rat, in modern methods of their destruction, and in the scientific ratproofing of premises."

This scientist, in commenting on the results which have followed the use of the outmoded and unscientific methods employed for centuries, and to which reference has

been made above, had this to say: "It has been found that trapping either by attractive bait in cage traps, by breakbacks (snap traps) and other empirical methods such as sticky boards, has produced a steady toll of rats for a period, but has failed to have an appreciable effect on the total population involved."²

Similar comments have been made by a number of eminent public health officials regarding the absence of satisfactory permanent results when such rodent control methods have been used, the consensus being that experience has shown them to be, at best, only palliative. A few of these comments are quoted:

"The only treatment which holds out any prospect of lasting relief from rat infestation is rat-proofing, both in ships and on shore in ports," is a statement made by Dr. Charles F. White, Chief Medical Officer of the Port of London, England, in his annual report for 1935.³

Public Health Bulletin 30, a United States Public Health Service publication, contains this statement: "Rat destruction is of doubtful value; as the rat population decreases, the breeding rate among survivors increases due to relatively increased food supply and harboring facilities; rat-proofing is of the greatest value as an antiplague measure."⁴

A Joint Committee of the Chamber of Shipping of the United Kingdom, in a report which was submitted to the British Government as to the need for carrying out the ratproofing of new ships of the British Merchant Marine, made the following statement: "The Committee did not attempt to deal with existing vessels, though in fact many British ships have been more or less ratproofed with very successful results. They commonly have no rats on board, and if any embark, their expectation of life is short, and they bear no families.... It is certainly worth while for an owner to get a report on the state of any vessel which is chronically rat-ridden in spite of fumigations and other precautions as ratproofing will, as a rule, put a stop to the trouble."⁵

These statements, founded on the experiences of public health officers and sanitary authorities in various parts of the world in their dealing with the rodent control problems, would seem to indicate very clearly that the solution that holds out the best prospect for permanency lies in ratproofing. The employment of this means would appear to be the answer to the question propounded in the early part of this paper, *viz.*: "What practical means can be employed?"

3. Ratproofing Program

To summarize, a program of ratproofing should include the following basic requirements:

1. Employment of an approved ratproof design which provides for the elimination of all unnecessary enclosed spaces within the structure of the building, its equipment, and fixtures.
2. Use of material which is ratproof in character, that is, material impervious to rat gnawing.

² M. T. Morgan, *J. Roy. Sanit. Inst.*, 61, 175 (1941).

³ Report of the Chief Medical Officer for the Port of London, England, for the year ending December 31, 1935.

⁴ U. S. Pub. Health Service, *Pub. Health Bull.* 30 (1910).

⁵ Report of the Joint Committee on Ratproofing of the Chamber of Shipping of the United Kingdom, and Liverpool Steam Ship Owners Associations, February, 1934.

3. Use of approved methods of construction and installation, including equipment and fixtures.

4. Provision for a regular, periodic inspection of building structures and equipment to insure permanent upkeep. Such inspections should be made by the operating officials as a part of their weekly program; and a record should be made of same.

As a guide to inspecting operators and managers in the items to look for and in the means of recording their findings, two forms are presented herewith and are suggested for use. They may be amended and modified to conform to the requirements of the individual establishments involved. These records of weekly inspections will be useful in furnishing a rodent and sanitary index of the building and its equipment. It is just as important for a manager to know what the rodent condition of his plant is, as to be kept informed about the quality of the raw material entering into the food product turned out by his establishment.

The program for ratproofing and its maintenance should include also the conversion of nonratproof fixtures and equipment already installed into any one of the ratproof types described in the standard publications on this subject issued by government public health agencies. Such a publication, entitled "The Rat and Ratproof Construction of Buildings," Supplement No. 131, to the *U. S. Public Health Reports*,⁶ contains a rather complete set of drawings, specifications, and suggestions for accomplishing ratproofing in old as well as new fixtures. When planning for the replacement of old fixtures or for their repair, the operator of a food plant would be greatly aided in preventing the incidence of rat life in such units if the suggestions made in the tabulation and specification contained in this publication were followed, that only fixtures and equipment of an approved ratproof type be installed in such establishments.

All accumulated trash, unserviceable and discarded articles, out-of-date records, etc., should be disposed of, and the custom of storing them in cellars, attics, lofts, and other out-of-the-way places be discontinued. Provision should be made for the systematic daily or weekly disposal of waste products and unserviceable articles through the cultivation of habits on the part of the operating personnel that will attain this objective. If this measure is put into effect as a routine administrative and operative procedure, there will be no accumulation of trash to provide rat harborage. If no rat harborage is present, there will be no colony rat life; and if there is no permanent rat life in a food establishment, there will be no risk of pollution of food products by rodent activities or excretions.

The use of standard forms for making a rodent investigation simplifies the procedure by directing the investigation into proper channels and by providing a check list. A report form of this type is shown on the following pages.

⁶ B. E. Holsendorf, "The Rat and Ratproof Construction of Buildings," *U. S. Pub. Health Repts.*, Suppl. 131 (1937). Drawings by P. W. Clark.

RODENT INVESTIGATION

District No.

Location..... Borough..... Date.....
Type of building..... How occupied.....
Owner of building..... Address.....
Others responsible—Agent..... Lessee..... Occupant.....
Name..... Address.....

1. Construction of building: Brick.....Concrete.....Frame.....Other.....
 2. Foundation walls extend 3 feet below surface? Yes.....No.....
 3. Foundation walls in good repair? Yes.....No.....
 4. Foundation walls free from rat harborage? Yes.....No.....
 5. Cellar floor ratproof? Yes.....No.....
 6. Cellar floor tied into sidewalls? Yes.....No.....
 7. Are outside openings into cellar and into roof space or attic protected to prevent entry of rats? Yes.....No..... If not, describe and locate.....
 8. Doorsills provided for outside doors to block out underneath space? Yes.....No..... If not, describe and locate.....
 9. If under sides of floor or ceiling rafters or stairways are sheathed, can rats gain access to spaces thus formed? Yes.....No..... If so, describe and locate.....
 10. Are openings around sewer, water, gas, electric lines protected against the entry or passage of rats? Yes.....No..... If not, describe and locate.....
 11. Any other openings in floors, ceilings, walls, doors, windows, which would admit rats? Yes.....No..... If so, describe and locate.....
 12. Accumulated refuse or old supplies in cellar, yard, court, areas, attic, rooms, halls, on roof or any other part of premises? Yes.....No..... If so, describe and locate.....
 13. Any rat harborage in fixtures and equipment or in any other place not noted above? Yes.....No..... If so, describe and locate.....
 14. Rat infestation found? Yes.....No..... If so, describe and locate.....
 15. RECOMMENDATIONS:

15. RECOMMENDATIONS:

RODENT CONTROL REPORT (FIXTURES)

Location.....Borough.....Date.....

Name.....

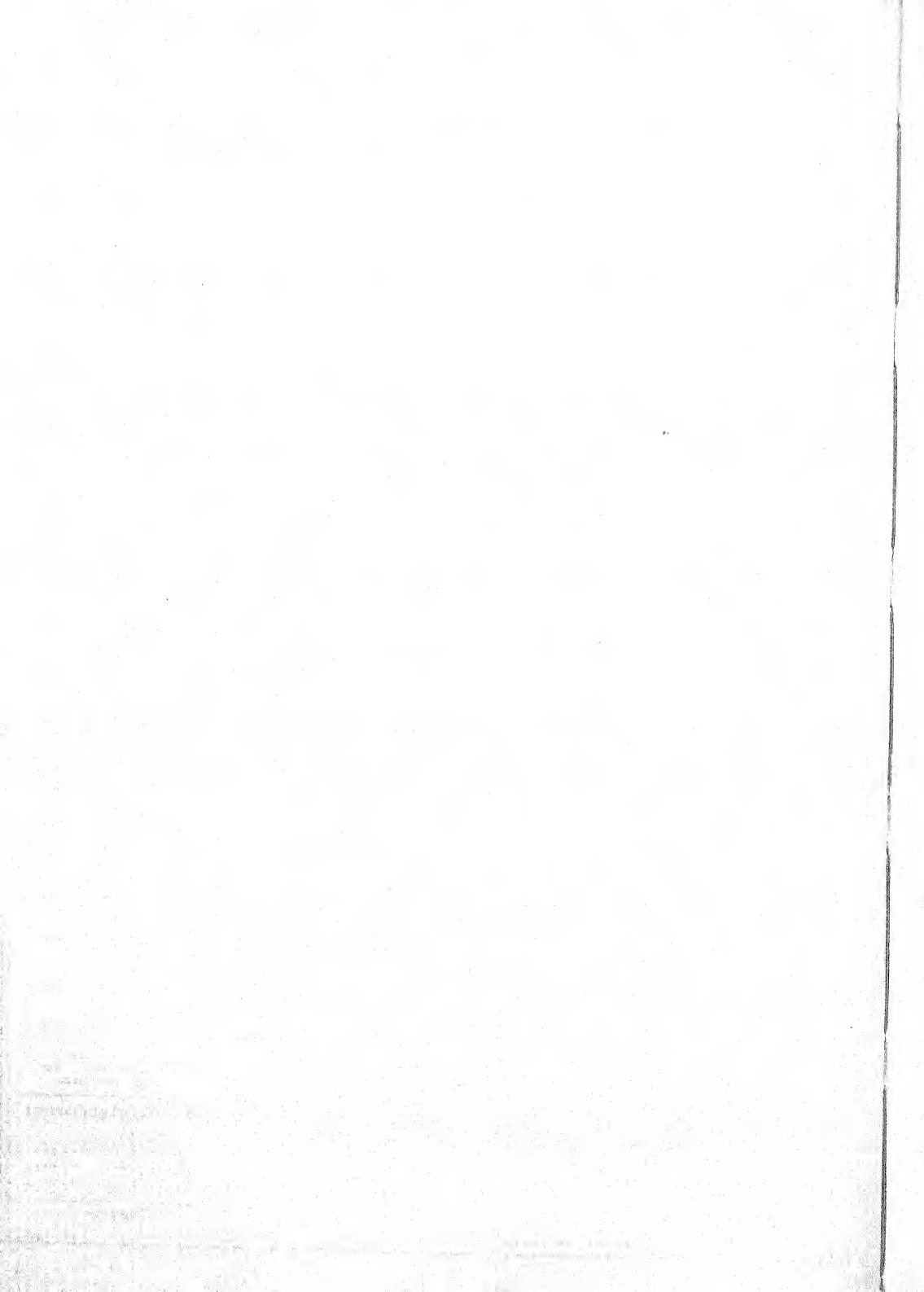
Type of establishment.....

Kind of fixture	Class of material of which made	Ratproof or nonratproof construction	How installed, ratproof or not	Description of type of harborage, if present
1. Counters.....	Metal Other	Wood	Ratproof Nonratproof	..... Space at bottom Space behind. On top. In fixture
2. Shelves.....	Metal Other	Wood	Ratproof Nonratproof	..... Space at bottom Space behind. On top. In fixture
3. Bins.....	Metal Other	Wood	Ratproof Nonratproof	..... Space at bottom Space behind. On top. In fixture
4. Lockers.....	Metal Other	Wood	Ratproof Nonratproof	..... Space at bottom Space behind. On top. In fixture
5. Showcases.....	Metal Other	Wood	Ratproof Nonratproof	..... Space at bottom Space behind. On top. In fixture
6. Desks.....	Metal Other	Wood	Ratproof Nonratproof	..... Space at bottom Space behind. On top. In fixture
7. File cases.....	Metal Other	Wood	Ratproof Nonratproof	..... Space at bottom Space behind. On top. In fixture
8. Cupboards.....	Metal Other	Wood	Ratproof Nonratproof	..... Space at bottom Space behind. On top. In fixture
9. Pantry lockers.....	Metal Other	Wood	Ratproof Nonratproof	..... Space at bottom Space behind. On top. In fixture
10. Work tables.....	Metal Other	Wood	Ratproof Nonratproof	..... Space at bottom Space behind. On top. In fixture
11. Iceboxes.....	Metal Other	Wood	Ratproof Nonratproof	..... Space at bottom Space behind. On top. In fixture
12. Refrigerators.....	Metal Other	Wood	Ratproof Nonratproof	..... Space at bottom Space behind. On top. In fixture
13. Stoves or ranges.....	Metal Other	Wood	Ratproof Nonratproof	..... Space at bottom Space behind. On top. In fixture
14. Steam tables.....	Metal Other	Wood	Ratproof Nonratproof	..... Space at bottom Space behind. On top. In fixture
15. Ventilating trunks....	Metal Other	Wood	Ratproof Nonratproof	..... Space at bottom Space behind. On top. In fixture
16. Floor gratings.....	Metal Other	Wood	Ratproof Nonratproof	..... Space at bottom Space behind. On top. In fixture
17. Kitchen sinks.....	Metal Other	Wood	Ratproof Nonratproof	..... Space at bottom Space behind. On top. In fixture
18.	Metal Other	Wood	Ratproof Nonratproof	..... Space at bottom Space behind. On top. In fixture
19.	Metal Other	Wood	Ratproof Nonratproof	..... Space at bottom Space behind. On top. In fixture

Describe below any unusual conditions as to harborage found. Also indicate the type and extent of corrective measures (ratproofing) recommended:

.....
.....
.....

Inspector



PART V
PRESERVATION



Chapter IX

THE DEHYDRATION OF FOODS

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It is almost axiomatic that the keeping quality of a food under natural conditions is related to its moisture content. But for man's intervention, the useful life of fruits, leafy vegetables, meats, fish, and many dairy products would be a matter of days, whereas, for some root crops and cereals, months may elapse without serious deterioration. Apart from dried herbs of use as condiments, there have come down to us through the ages two types of dried food: one, the dried fruits, especially dates, figs, and raisins, products of Arabia and the Mediterranean region, valued for their high sugar content; the other, meats and fish, products of northern countries, and which originally must have been preserved either as a cheap and abundant source of protein, such as the dried salted cod,¹ or as an emergency source during winter or drought when fresh meat was scarce. Pemmican and biltong are examples in this category. More recent additions are dried eggs and milk powder, of widespread use institutionally, but not as yet staples with the public at large.

The noteworthy absence of vegetables deserves comment. Corn and peas, which could be kept satisfactorily if allowed to mature normally, have been dried under conditions which may have tended to cause partial hydrolysis of their starch, or, picked immature, to contain relatively less starch and more sugar. An example is "samp," the cooked dried corn of the early settlers. It is seldom realized how great a change in Western eating habits was effected in the 17th and 18th centuries. The carrot, for example, was developed horticulturally within the last 400 years; and, although the cabbage family was cultivated in Roman times, its potentialities were not fully exploited until the days of "Turnip" Townshend during the Walpole administration. Apart from China, vegetables were not available for extensive drying, and they had few qualities which rendered people desirous of so doing.

In a paper entitled "Commercial Dehydration: A Factor in the Solution of the International Food Problem," Prescott and Sweet in 1919² gave a brief historical review. Their expectations as to the future of the dehydration industry have been so far-unfinished in the period between the two world wars that it behooves us to examine

¹ The *bacalao* of Spain and tropical America (*bacalhau* in Portugal and Brazil), mentioned by Froude as the summer occupation of the Spanish crews at the time of the Armada. The kippered salmon and herring apparently antedate the cod.

² S. C. Prescott and L. D. Sweet, *Ann. Am. Acad. Pol. Sci.*, 83, 48, 172 (1919).

the problem with extreme caution. In general, the market for dried foods of the types mentioned was maintained, and in many cases extended, e. g., dried eggs and milk powder. In other respects, a vicious circle was created, a cheap product requiring cheap labor, low cost, and inevitably inferior quality. This does not apply to certain widely accepted foods such as the kippered herring and the bloater, where definite tastes had been acquired. It does, however, apply to the cut dried fruits, preventing desirable sanitary reforms which would have improved the product, and particularly to dried vegetables, where, except for onions and a few specialty crops, the quality was so inferior that the dried product was virtually unmarketable.

It is difficult to determine to what extent these objections have been surmounted. Most of the properly dried products are sufficiently palatable if stored at reasonable temperatures, say below 75° F., for short periods of time. Many are edible if stored considerably longer; but few are really satisfactory if stored above 90° F. for a few months. Consequently, peacetime demand may well be limited to special situations, such as week-end or mountain trips, though a few new items such as dehydrated soup stocks have met with some success in the past few years. Successful storage is a continuous fight against moisture pickup, insects, and inevitable deterioration of the food itself by chemical or biochemical processes. Furthermore, reconstitution and cooking prior to consumption in general still require more time and skill than for canned, frozen, or fresh foods.

The causes of failure after the last war were therefore twofold: the inferior quality of the stored product, and difficulties in preparation for the table. Both may contribute to failure again. It seems likely, however, that several additional products will survive on a larger scale, including superior grades of spray dried egg and milk powders, dried potatoes, soup stocks (in use as early as 1770 according to Schofield³), and some specialty products such as a dried orange juice powder of high quality. Beyond this, it is unwise to venture a prediction.

It may, however, be pointed out that the time for accustoming people to dehydrated products is limited to the emergency; that the causes of previous failure are still not removed, and that dehydration must be undertaken in plants already built, with little chance of basic or revolutionary change until the war is over, when the people will again have free choice between the various foods, canned, frozen, dehydrated, or fresh.

I. DEHYDRATION PRINCIPLES

A convenient, though arbitrary, definition of dehydration applied to foods is "drying under controlled conditions of temperature and humidity to a specific end point in a given time." Water may be evaporated in one of two ways, isothermally or adiabatically. While it is not feasible to present a detailed discussion of the principles involved, the following comments may clarify many of the construction and operational problems involved in dehydration. In vacuum drying, the process is largely isothermal. The same applies to some extent in methods in which radiant heat is

³ M. Schofield, *Food Manuf.*, 18, 187 (1943).

used. The spray drier would seem to be a special case of almost instantaneous adiabatic evaporation. The typical adiabatic process is found in the hot blast tunnel dehydrater, with air velocities of 500 to 1000 or more linear ft. per min., whereas kilns, such as the apple evaporators, or houses for drying and smoking the kippered herring, have air flows of the order of 100 ft. per min. Foods are dried within a relatively narrow temperature range; and the composition of the exhaust air, even when nearly saturated, is not widely different from that of the entering air (expressing the composition in terms of pounds of water vapor per pound of dry air). As a result, the wet bulb temperature for the adiabatic process will be rather constant. For the air-blast tunnel dehydrater, 30 to 60 ft. long, with a dry bulb temperature drop of 30° F., the wet bulb temperature will normally vary less than 2° F. Heat is conveyed by air or flue gas to the product on trays stacked on cars in a tunnel. The following calculation is given for heat requirements and air flow in a typical case.

Let us assume carrots at 88% moisture are dried to 4% moisture in a tunnel with a capacity of 15 fresh tons per 24 hours, that the outside air at 70° F. is saturated with water vapor, and that the air is to be heated to 160° F., and is exhausted from the tunnel at 120°. Under these conditions, the air at 70° contains 0.01 lb. water vapor per lb. dry air. It is heated to 160° without change. If exhausted at 120°, it will have picked up an additional 0.009 lb. water vapor as a result of evaporation by adiabatic cooling.

Allowing for trimming losses in the 15 tons of carrots, over 20,000 lbs. of water must be removed, i. e., about 14 lbs. per min. Consequently 14/0.009 or 1550 lbs. of air (about 25,000 cu. ft.) are required per min. If the free cross sectional area of the tunnel is 30 sq. ft., the linear air velocity must be over 800 ft. per min. To heat the outside air, at 70° to 160°, approximately 22 B. t. u. per lb. of air will be required. This, cooled to 120° by passage through the tunnel, evaporates 0.009 lb. water, so that the heat required per lb. water evaporated is 22/0.009 or 2300 B. t. u.

Inasmuch as the latent heat of vaporization of water is about 1080 B. t. u. per lb. (including the heat required to raise the water to the wet bulb temperature), there is a high heat loss, represented by the difference between 2300 and 1080 B. t. u., per lb. of water evaporated.

These figures, of course, represent the theoretical minima in the two cases, assuming utilization of the heat solely for the purpose of evaporating the moisture. A discussion of operational heat losses is given by Cruess and Mackinney.⁴ It is frequently possible to reduce this difference by recirculation of part of the hot exhaust air, but not with vegetables to be dried to low moisture, because the equilibrium humidity for these products at such a moisture level is too nearly the humidity at the end where the product is discharged dry for effective drying to be continued. However, with prunes, which are dehydrated to 18% moisture, $\frac{3}{4}$ to $\frac{5}{6}$ of the exhaust air may be recirculated. Dehydration principles are discussed as a problem in chemical engineering by Walker, Lewis, and McAdams.⁵ Equilibrium moisture humidity relations have been studied by Makower and Dehority for vegetables,⁶ and for fruits by Schwarz.⁷

⁴ W. V. Cruess and G. Mackinney, Calif. Agr. Expt. Sta., *Bull. 680* (1943).

⁵ W. H. Walker, W. K. Lewis, and W. H. McAdams. *Principles of Chemical Engineering*. McGraw-Hill, New York, 1923.

⁶ B. Makower and G. L. Dehority, *Ind. Eng. Chem.*, 35, 193 (1943).

⁷ T. A. Schwarz, *Food Industries*, 15, No. 9, 68 (1943).



II. DRYING PROCEDURES

1. Sun Drying

In a discussion of the drying of foods, some mention must be made of sun drying, since this procedure is followed in preparing practically all dried apricots, figs, nectarines, pears, peaches, raisins, and a large proportion of the dried prunes; only small tonnages of raisins, figs, and peaches are dehydrated, although there is an upward trend in their production.

Apricots, nectarines, peaches, pears, and prunes are dried on trays and exposed to the sun in a drying yard. Trays are usually stacked when the fruit is about two-thirds dry. Details of sun drying equipment and field layout including location, sanitation, and transportation of the fruit have been discussed by Mrak and Long.⁸

Undipped raisins are dried in most instances on 2×3 ft. paper or wooden trays between the rows in the vineyard. Frequently the trays are inclined on a bank of earth in order to secure better exposure to the sun. Drying is slow, so the fruit must be turned at least once during the process. When it is nearly dry, the paper trays are rolled into "biscuits" and allowed to remain on the field for several days for curing. Wooden trays are stacked.

In Australia and South Africa, to avoid rain hazard during the drying season, grapes are dipped in an alkali-olive oil emulsion and placed on shaded shelves of chicken wire for drying. In some of the Mediterranean areas, it has been customary to dry the grapes directly on the ground, which is very unsanitary.

Dates and figs undergo considerable drying while on the tree. In many areas, dates are considered sufficiently dried when harvested. Figs usually fall to the ground when from one-half to two-thirds dried.

2. Drying by Mechanical Driers

There are several types of driers in use for the dehydration of foods, the type employed depending to a large extent on the nature of the product to be dried. See page 95. Fruits and vegetables, for example, may be dried satisfactorily in a tunnel dehydrator, while milk and eggs are usually spray dried. Marshall⁹ has classified driers suitable for foods into ten general types. Informative line drawings of types of driers used for foods have been published by Rousseau.¹⁰ In general, tunnel or compartment driers are in most common use for drying solid food materials, although continuous belt driers are becoming more common. Natural draft evaporators, however, are still widely used for apples and hops.

(a) Tunnel Driers

The tunnel and truck dehydrator, described by Van Arsdel,¹¹ is essentially a forced circulation, hot air drier, arranged with the moist material spread on trays to expose a

⁸ E. M. Mrak and J. D. Long, Calif. Agr. Expt. Sta., *Circ.* 350 (1941).

⁹ W. R. Marshall, *Heating, Piping, Air Conditioning*, 14, 527 (1942).

¹⁰ F. R. Rousseau, *Food Industries*, 11, No. 12, 687 (1939).

¹¹ W. B. Van Arsdel, *Food Industries*, 14, No. 10, 43; No. 11, 47; No. 12, 47 (1942).

large drying surface; the material may be carried in semicontinuous flow through the equipment and emerge substantially dry. In tunnels of the usual length, the problem may be analyzed as though it were truly continuous.

The tunnel dehydrater consists of a drying tunnel and an air heating and circulation or plenum chamber. Trucks of moist material enter at one end of the tunnel and progress forward to the exit or dry end. Both ends are equipped with tight fitting doors to minimize heat losses. The length of the tunnel varies with the design of the drier and material to be dried. One or more fans are arranged according to the particular design, although a common procedure is to locate them near one end of the heating chamber. The heating equipment may be located to one side, above or below the drying tunnel. In large operations, it is customary to construct several tunnels side by side rather than to increase the size of a single one. In such cases single heating and fan units frequently serve two drying tunnels.

Heating Systems.—Air to be passed over the food may be heated by direct heat, direct radiation, or indirect radiation. By direct heat is meant the addition of heat to the air used in drying by direct mixing of the product of combustion and the air in the plenum chamber without the intervention of furnace walls or flues. This can only be done where there are no combustion products that might damage the fruit or vegetable. This heating system is particularly well adapted to the use of natural gas as a fuel. Oil is less satisfactory owing to danger of smudging. Coal or wood cannot be used in direct heat systems. The advantages of direct heat are: high fuel efficiency, low cost of installation and upkeep, and instantaneous temperature regulation because of the absence of stored heat in flues. The disadvantages are: possible contamination of the food by products of incomplete combustion and the necessity of using a high-grade fuel. Direct radiation refers to the absorption of heat by air from burning fuel by radiation through the furnace wall, flues, or radiators. This system offers the advantage of freedom from contamination with combustion products even though a poor grade of fuel is used. Disadvantages are: expense of installation and upkeep, lack of instantaneous temperature regulation because of heat storage, and lower fuel efficiency resulting from stack losses.

Indirect radiation, or the generation of heat at a distant point and its transportation to a point at which air is to be heated, by means of steam or hot water radiators, is used extensively in areas where coal or low-grade fuels must be used. The advantages of such a system are: automatic regulation, no limitation of the type of fuel that may be used, and the distribution of radiators where desired. The disadvantages of indirect radiation are expense of installation and upkeep, and low fuel efficiency.

For economy, a considerable proportion of the drying air is often recirculated through the heater and again over the drying material. This also prevents "casehardening," a process in which the outside layers of a piece dry so rapidly that the center remains moist. Casehardening is more likely to occur in fruits and peas than in other products.

Air Circulation.—Several different arrangements for air circulation are in use in tunnel dehydraters. These variations may result in considerable differences in

capacity, efficiency, and ease of operation. Van Arsdel¹¹ has described and illustrated some of the more important arrangements of air flow used in tunnel dehydrators.

Countercurrent.—The better known arrangements for air flow used in tunnel dehydrators may be classified as countercurrent, parallel-current, crossflow, center inlet, center exhaust and multiple-stage. When the countercurrent system is used, air and fruit move in opposite directions through the drying tunnel. Fresh air is mixed with some recirculated air, heated, and then forced through the tunnel from the dry end to the wet end, where it is partially exhausted and partially recirculated. This system is widely used in the West for drying prunes and grapes. Its use for fruit is advantageous because the gradual movement from the cool to the hot end of the tunnel minimizes bleeding (juicing) and undesirable color and flavor changes. In contrast with vegetables, most fruits, except apples, must be dried slowly in relation to the temperature used to prevent damage to the product.

Parallel-Current.—The parallel-current construction is similar to that of a countercurrent tunnel, but the movement of air is reversed. The product to be dried enters at the hot or wet end and moves in the same direction as the air flow. It is generally safe to use a higher temperature than that used in the countercurrent tunnel for, at the wet end, the temperature of the drying food will be near that of the wet bulb. At the dry end, the air is cool and moist, and will not dry the product to completion unless very light tray loadings are used. This system is unsatisfactory for slow drying materials such as prunes.

Crossflow.—The crossflow or combination compartment and tunnel arrangement is such that air flow is transverse to the axis of the tunnel in a back-and-forth manner through successive trucks. This system is used to a considerable extent for dehydrating fruits, but is a difficult one to operate and control.

Center Inlet.—In the center inlet arrangement, air enters at the center of the tunnel and travels toward the two ends. The material to be dried travels counter to the air flow at the wet end, and parallel in the dry end. The highest temperature is at the center of the tunnel rather than at one end. These tunnels are used for drying fruits and, to a lesser degree, vegetables.

Center Exhaust.—The center exhaust system is the reverse of the center inlet. Heated air enters at the two ends and circulates toward the center, leaving the tunnel at or near the center. Moist material moves in the same direction as the air flow at the wet end and counter to the air flow at the dry end. This system, which was originally introduced by Eidt¹² for apples, is proving satisfactory for products which give up moisture readily, such as vegetables. Its suitability for slow drying fruits such as prunes is doubtful because of the high initial temperature favoring bleeding.

Multiple-Stage.—The multiple-stage tunnel drier consists of two or more tunnel sections which are controlled independently for air flow and temperature. The favored arrangement is to use parallel flow in the initial tunnel, and counterflow in the

¹¹ C. C. Eidt, Can. Dept. Agr., *Tech. Bull.* 182 (1938).

second stage. This system is proving very satisfactory for vegetables because the rapid drying favors retention of quality. In some instances, final drying is accomplished by the use of bins, through which heated air can be circulated.

(b) *Conveyor Driers*

In this type of drier, an endless belt carries the material through the tunnel. The advantage of such a system lies in automatic operation, and low labor requirement. Disadvantages are high cost of installation and comparatively low output per unit.

(c) *Cabinet Dehydrators*

These driers are arranged for batch operation, and usually at a constant temperature, though humidity may decrease during the progress of drying. Air flow may be across or through the trays, with or without recirculation. Cabinet driers have the advantage of flexibility, although the production may be comparatively low, and the labor requirement somewhat greater than for a tunnel dehydrator.

(d) *Evaporators*

Natural draft evaporators were used quite extensively during the early development of industrial dehydration. Today, however, they are used almost entirely for hops and apples. These driers are constructed as kilns with slatted floored drying rooms located over a heater. The material to be dried is spread on the floor in a layer about 10 inches deep. Hot air passes through the pieces and leaves the drying chamber through a roof vent. Sometimes fans are installed in the roof vents to increase the movement of air through the drying material. These plants are slow and inefficient, and lack control.

(e) *Drum Driers*

These driers have been discussed and well illustrated by Rousseau.¹⁰ They are designed for handling solutions, fruit and vegetable purees, pastes, and sludge materials. Drum driers may be classified as single- or double-drum atmospheric or vacuum types. In operation, the material is fed on the outer surface of a steam heated revolving drum, the rotation of which is such that, by the time the adhering material has moved to the position for removal, the product is dried. Drum driers are used successfully in the production of powdered cranberries, tomato cocktail, pea and bean soups, and apple flakes.

(f) *Vacuum Driers*

These driers are constructed to permit drying at low temperatures and under low pressures in the absence of air. Although not so widely used as the types already discussed, they are advantageous for products with a low moisture diffusion rate, materials with low critical temperatures, and those which cannot be exposed to air when

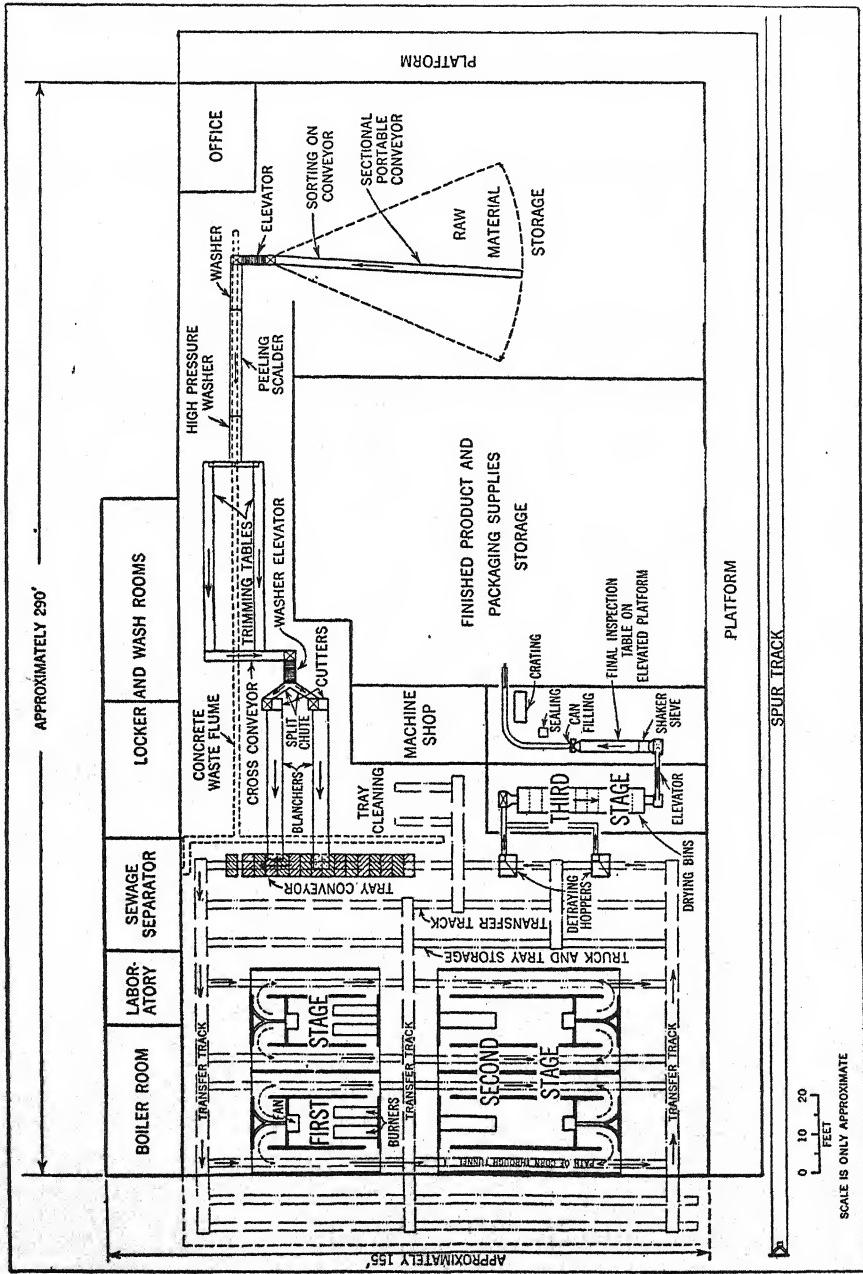


Fig. 43.—Lay-out for a 100-ton multiple stage vegetable dehydration plant with arrows indicating the flow of materials.

(Courtesy The Agricultural Research Administration.)

drying. They are used commercially for preparing "apple nuggets," fruit and milk powders, meat, and certain specialty products. Vacuum driers are used for products which cannot be tumbled. Starch and similar products which can be tumbled and do not adhere to the heating surface, are dried in vacuum rotary driers, equipped with a spiral agitator to insure mixing.

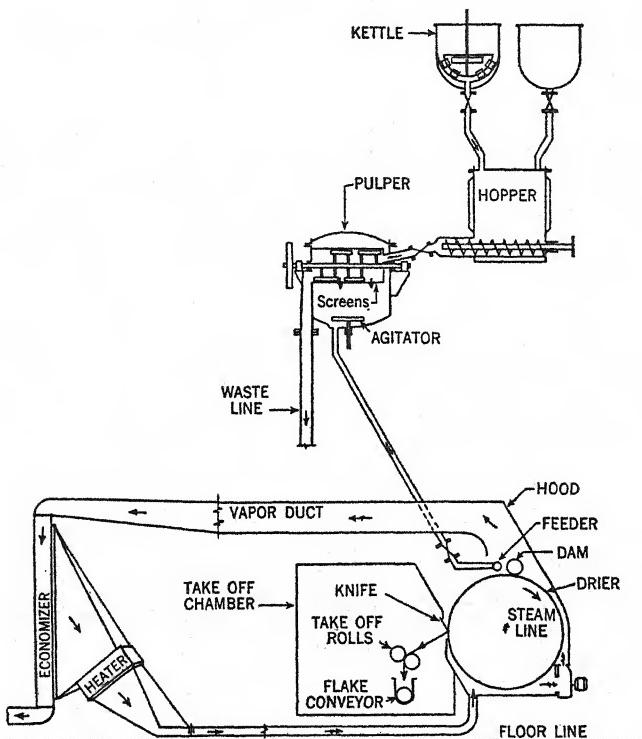


Fig. 44.—The Sardik process chart indicates steps used in the drum drying of tomato puree and of apple pulp in the preparation of tomato powder and apple flakes. This type of drier is occasionally used for milk. (Courtesy Sardik Co., Lockport, N. Y.)

A comparatively new use for vacuum dehydration is the so-called blood plasma procedure. This involves freezing of the material and subsequent drying in a high vacuum. Although used commercially for blood plasma, it is still in the experimental stages for foods. Low-temperature vacuum drying offers promise as a procedure for preparing orange juice powder.

(g) *Rotary Driers*

These driers are commonly used in chemical industries, but have had a more limited use in food drying. Recently the "Roto-Louvre" drier has been used successfully for drying meat, and another type is being tried for potatoes.

(h) *Spray Driers*

The use of spray drying for milk, eggs, and vegetable soups has increased considerably because of the high degree of success of the operation. Materials are handled in one step from liquid to powder, and drying is almost instantaneous. There are two systems of spray drying, according to the method of atomizing the material in the drying chamber. In one system, the material to be dried is pumped under high pressure through spray nozzles located at the center of air nozzles. Atomization at the nozzle is so effective, and the turbulent action so violent, that drying is practically instantaneous. The powdered material falls to the bottom of the drying chamber, at a relatively low temperature.

The spray wheel system of spray drying consists of a centrifugal atomizer revolving at a high rate of speed, but dependent on design and the nature of the product. There are a number of designs involving this type of equipment.

(i) *Bin Driers*

Bin driers are used commonly on the West Coast for dehydrating walnuts, although the present trend is toward the construction of upright multiple-stage driers. Walnuts are collected in metal bins through which heated air can be circulated under controlled conditions. There are a number of designs, some of which permit air recirculation. Nichols, Moses, and Glenn¹³ have discussed walnut bin driers in detail.

In the dehydration of vegetables, particularly onions, it has been found difficult to reduce the moisture content to the necessary level when tunnel or other air-blast driers are used. This slow rate of moisture removal during the latter stages of drying is costly, and reduces production unless bin driers are used. It is becoming a common procedure, therefore, to remove the vegetable from the primary drier where the drying rate is low, and to finish drying in bins through which heated air can be circulated. In some instances, the air is dehumidified before passage through the bin.

(j) *Other Possibilities*

The use of radio-frequency energy to evaporate moisture has received considerable publicity. It is apparently planned as an adjunct to conventional drying (where the moisture is reduced to 4 or 5%) to lower the moisture content further, below 1%. Vegetables would be compressed according to one report, and exposed to radio waves of suitable frequency. It would seem of utmost importance to remove the water promptly from the center of the vegetable block, to avoid heating the product; and it is not clear how this is to be accomplished.

Infrared lamps have been installed in a plant for natural dried cod¹⁴ to reduce the moisture from about 60 to 43%. Based on the production figure of about 4000 lbs. per 7.5-hr. shift, 420 kw.-hrs. are required; and one may estimate that about 1000

¹³ F. P. Nichols, B. D. Moses, and D. S. Glenn, Calif. Agr. Expt. Sta., *Bull. 531* (1932).

¹⁴ L. V. Burton, *Food Industries*, 15, No. 12, 80 (1943).

lbs. of water have been evaporated. It is pointed out¹⁵ that the value of the infrared lamp lies in the increase in rate of heat transfer to the product over that obtainable in the ordinary blast tunnel. It is instructive to compare a possible unit for carrots¹⁵ with the example given earlier in this chapter. The oven length would be about 40 ft., and the oven would contain 850 reflector lamps of 250 watts each. The capacity of the oven is estimated at 225 lbs. wet carrots per hour. The estimate is based on removal of more than 90% of the original moisture in 11 minutes. However, over 99% of the original must be removed to reduce carrots to 5% moisture, and some type of conventional tunnel or finishing bin would be needed. Commercial operation may well be restricted therefore to special cases and limited tonnages, unless high-priced products warrant greater speed. It is difficult to see how the method could be applied economically to prunes or grapes, for which the drying is dependent on a slow rate of moisture diffusion.

III. TREATMENT PRIOR TO DRYING

For sanitation, storage stability, flavor retention, and nutritive qualities, foods to be dried are in most instances subjected to some type of pretreatment. Prior to drying most vegetables are washed, trimmed, subdivided, and blanched; fruits are usually dipped or sulfured; milk is preheated; and meats are cooked.

1. Washing

All vegetables should be thoroughly washed, particular care being taken to remove all adhering dirt from the root crops by use of heavy sprays and rotary washers. Fruits are not always washed, although the procedure is advisable. Soft fruits, such as apricots, must be handled carefully in batch or low-pressure water spray washers. Apples and pears should be washed in order to remove arsenic and lead spray residues, as well as other foreign materials. Continuous acid or acid and alkaline spray washers¹⁶ have proved most effective for this purpose. It is also customary to wash the cut surfaces of pears with sprays of water in order to remove particles of foreign material adhering to the white surfaces. Eggs should be cleaned before cracking, as a means of minimizing bacterial contamination.

2. Peeling and Subdivision

Root vegetables, apples, and sometimes clingstone peaches are peeled prior to drying. This is accomplished by use of abrasion, refractory, lye, hot brine peelers, or high-pressure steam for root vegetables, mechanical knife peelers for apples, and dilute lye for clingstones. The root vegetables are then cut into cubes, julienne strips, flakes, or slices; cabbage is cut into shreds. Potatoes may also be riced and dried into powder form. See Fig. 45, page 297.

¹⁵ F. M. Tiller, E. E. Litkenhous, and W. Turbeville, *Food Industries*, 15, No. 10, 77 (1943).

¹⁶ E. M. Mrak and J. D. Long, Calif. Agr. Expt. Sta., *Circ.* 350 (1941).

Of the fruits, prunes, grapes, berries, and cherries are dried whole, although the latter may be pitted. Apricots, nectarines, and peaches are halved and pitted, pears halved, stemmed, and the calyx removed, and apples peeled and sliced or sectioned. Some unpeeled apple sections are also dried for use in the manufacture of pectin, vinegar, or jelly.

Meats are reduced to small cubes, or a coarse hash form, although fish may be filleted or ground. Soup powders are usually prepared from thick purees, and milk and egg powders by the drying of the original liquid.

In a process described by Stateler,¹⁷ meat cubes with very little added water are precooked at 165 to 175° F. while under agitation for about 30 min. The objects of this procedure are inactivation of the meat enzymes, reduction of the total moisture content of the meat from about 72 to about 50%, and coagulation of meat juices. This in all probability also reduces the bacterial count. The meat is ground after cooking.

Eggs according to Mulvany¹⁸ are not preheated prior to drying while Jack and Henderson¹⁹ consider that powdered milk has better keeping qualities if heated prior to drying.

3. Dipping

Dipping, which is used primarily for fruits, involves immersion of the product in an alkaline solution prior to drying. It is used primarily for fruits dried whole, especially grapes, although it cannot be used for berries, with the possible exception of cranberries. Dipping facilitates drying by forming very fine checks or cracks in the skin and removing the waxy coating. Sodium carbonate and lye solutions (0.5% in strength, or less) are used. The temperature of the dipping solution usually ranges from 200 to 212° F. Concentration, temperature, type of dipping solution, and time of immersion vary with the condition of the fruit being treated. In Australia and certain of the Mediterranean countries, the dipping solution for grapes is an emulsion of olive oil and carbonate or lye, or both. Immersion in the emulsion favors retention of a light color, which is correlated in part at least, according to Hussein and Mrak,²⁰ with inactivation of the peroxidase system.

Excessive dipping causes prunes to lose juice during dehydration. For this reason there has been a tendency to omit the alkali and immerse the prunes only in hot water. Dipping in a lye solution is essential when drying is done in the sun.

4. Sulfuring

Fruits.—Before cut fruits and sulfur- or Golden-Bleached raisins are placed in the drying yard or the dehydrater, they are exposed to sulfur dioxide gas. Frequently,

¹⁷ E. S. Stateler, *Food Industries*, 14, No. 11, 52 (1942).

¹⁸ H. A. Mulvany, *Food Industries*, 13, No. 12, 50 (1941).

¹⁹ E. I. Jack and J. I. Henderson, *Food Industries*, 14, No. 3, 50 (1942).

²⁰ A. A. Hussein, E. M. Mrak, and W. V. Cruess, *Hilgardia*, 14, 349 (1942).

apples are dipped in a solution of sodium bisulfite, or of sulfur dioxide. The trend is toward more intensive sulfuring of fruits. The sulfur dioxide absorbed by the fruit serves to maintain an attractive color, prevent spoilage, repel insects, and preserve certain nutritive qualities. Sufficient sulfur dioxide must be absorbed by the freshly prepared material to allow for losses that occur during drying and subsequent storage.

Fruit is sulfured by placing it in a closed compartment with burning sulfur. Vegetables are treated by immersion in sulfite solutions. The sulfuring house and burner are essentially simple equipment; but careful attention must be given^{16, 21} to certain details of construction and operation. Absorption and retention of sulfur dioxide is influenced by the temperature, time, and concentration of sulfuring, and the condition, nature, and variety of material being sulfured. Immature fruit displays a greater absorption but poorer retention than fully mature fruit. Higher sulfuring temperatures tend to reduce absorption, but greatly facilitate the retention of sulfur dioxide. Losses are greater in sun drying than in dehydration.

Desirable levels of sulfur dioxide in dried fruits are, in parts per million: apricots, 3000; peaches and nectarines, 2500; pears, 2000; apples, 1500; and Golden-Bleached raisins, 1000.

Vegetables.—Treatment of vegetables with sulfur dioxide gas must logically come after blanching. Because they absorb the gas rapidly, the sulfuring time must be short. Current specifications for cabbage require 750 to 1500 p. p. m. of sulfur dioxide in the dry product. Operators have, in general, preferred sulfite solutions either in a dipping tank or applied as a spray. The spray applied as a dilute solution on cabbage in the blancher has been discussed by Mackinney and Howard.²²

5. Blanching

Blanching consists in partial cooking, in steam or hot water, of the food prior to dehydration. With most vegetables it is beneficial in improving keeping qualities. The following points may be considered advantageous:

- (a) Marked reduction in drying time.
- (b) Rapid inactivation of enzymes capable of causing deterioration.
- (c) Expulsion of air from the tissues.
- (d) On reconstitution, a less tough product.
- (e) In several cases, notably carrots and cabbage, delay in the development of off odors and flavors.
- (f) On storage, frequently a better retention of carotene and ascorbic acid.

The above advantages outweigh the following disadvantages:

- (a) Cost of installation and operation of blancher.
- (b) Inevitable loss in soluble solids, even where steam is used.

²¹ J. D. Long, E. M. Mrak, and C. D. Fisher, Calif. Agr. Expt. Sta., *Bull. 636* (1940).

²² G. Mackinney and L. B. Howard, *Food Industries*, 16, 355 (1944).

So far, little attention has been paid to rapidity of blanching. Tests are usually confined to catalase and peroxidase, and are aimed at determining completeness of enzyme inactivation. It has been found by Weier and Mann²³ for carrots, rutabagas, sweet potatoes, and parsnips, but not in potatoes, that many industrial samples contain hydrolyzed starch, whereas, if the temperature reaches 100° C. rapidly, within 30 sec., there is gelation but no hydrolysis. If the sample is held at 50° for a few minutes, the starch in the above vegetables may be almost completely hydrolyzed. A single industrial sample may be exceedingly variable in the distribution of starch in these various forms, as a consequence of uneven blanching. It is interesting to note that potato amylase is apparently inactivated prior to reaching the temperature for starch gelation, as no hydrolyzed starch has been found by Weier and Mann²³ in this vegetable.

The gelation of starch grains and their hydrolysis can be followed under the microscope with iodine solution. No such simple test is available for the first products of action of other enzyme systems, such as oxidases. Present criteria are therefore thoroughly inadequate, and possibly unsound. There is no evidence that the form or state of starch has any effect on keeping quality in carrots; but it should be clear that enzyme inactivation may include a period of considerable activity, and there is no easy means of determining whether this is beneficial or adverse.

Continuous blanchers are favored over the batch type. Treatment normally involves from 2 to 10 minutes of exposure to live steam. Series blanching in hot water is advocated in some countries, and the solids content of the water is maintained at a certain level in an effort to overcome losses by leaching.

Expulsion of the air from the tissues has two important effects. In vegetables, if the tissue is collapsed, the cells beneath the surface are protected effectively from the adverse effects of oxygen from the air. This is particularly noticeable in products high in starch, such as potatoes. Possibly this is one reason why potatoes are considered a most satisfactory vegetable to dry. In fruits, such as apricots, peaches, and pears, it provides the translucent effect desired by the trade, hitherto only attainable by exposure to the sun. This process was discussed recently by Mrak *et al.*²⁴

It has been shown by Crafts²⁵ that unblanched fruit contains innumerable small air bubbles, strikingly absent from the blanched samples. Sulfuring, that is, exposure to sulfur dioxide fumes, has a similar effect, but somewhat oddly, on dehydration, the bubbles re-form in the absence of the blanching step. The composition of the gas in such bubbles in these circumstances is a matter of conjecture. While the oxygen content is almost certainly low, so that oxidative changes may be unimportant, the desired translucence is of course lost.

In some cases, the blanching is actually a complete cook, either for sanitary reasons, owing to dangers of spoilage, or, as in beans, for ease in reconstitution and subsequent handling.

²³ T. E. Weier and L. K. Mann, personal communication.

²⁴ E. M. Mrak, H. J. Phaff, C. D. Fisher, and G. Mackinney, *Food Industries*, 15, No. 4, 59 (1943).

²⁵ A. S. Crafts, *Food Industries*, 16, No. 3, 76 (1944).

IV. DETAILED PROCEDURES

1. Cut Fruits

(a) Apples

Because of the intensive spray program used in the production of fresh apples, they should be washed thoroughly to remove arsenic and lead residues. Acid washes are described by Haller, Smith, and Ryall.²⁶ Apples may be peeled and cored by hand or by motor-driven machines, and then are sulfured whole or after slicing.

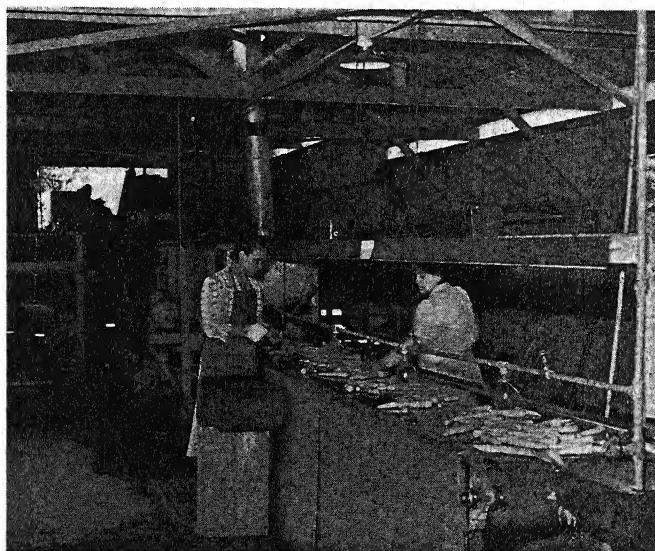


Fig. 45.—View of trimming belt in preparation line in a carrot dehydration plant.

Peeled and cored whole fruit is usually sulfured by conveying the fruit on a draper through a tunnel containing the fumes of burning sulfur. The period of exposure ranges from 10 to 20 min., and the concentration of sulfur dioxide fumes is approximately 1% by volume, since comparatively little sulfur dioxide is absorbed by the fruit. In certain areas, the fruit is sliced after peeling, spread on trays, and then sulfured in a standard chamber-type sulfuring house. Under these conditions, the absorption of sulfur dioxide is comparatively greater because of the increased surface area of the fruit, the higher concentration of sulfur dioxide fumes in the house, and the use of a longer sulfuring period. This procedure is the recommended type for gas sulfuring. A third method of sulfuring apples is immersion of the peeled whole fruit in a solution of sulfuric acid, the concentration of which may range from $\frac{1}{4}$ to about

²⁶ M. H. Haller, E. Smith, and A. L. Ryall, U. S. Dept. Agr., *Farmers Bull.* 1752 (1935).

2% sulfur dioxide. The time of immersion varies greatly with the individual operator, ranging from a few minutes up to 5 or more. Occasionally salt is added to this bath or to one in tandem for use prior to immersion in the sulfurous acid solution, to retard the peroxidase activity. The addition of a slight amount of sodium citrate to one of the baths apparently facilitates retention of sulfur dioxide by the fruit. In cases in which the whole fruit is sulfured, it is sliced thin after sulfuring by the use of a rotary slicer. Sometimes the fruit may be cut into quarters or eighths.

If the fruit is dried in an evaporator, it is spread on the slatted floor to a depth of about 10 inches, drying taking place slowly over a period ranging from 9 to 18 hrs. It is advisable to turn the fruit by shoveling at least once during the drying operation. Fruit dried in a dehydrater is spread, after slicing, to a depth of 3 or 4 in., on trays and the drying time is appreciably shortened. The temperature used in a dehydrater depends on the type used. With the center exhaust system, the initial temperature may be as high as 180° F., and that in the secondary stage about 20 to 30° less. With countercurrent air flow, the maximum temperature is about 170°. Recirculation when drying apples is less necessary than for other fruits because of the rapid loss of moisture.

The dried apples are removed from the driers, and stored in 50-lb. boxes pending packing or shipment to the packing house. Although apples are stored in bins, this procedure is inadvisable because it favors mechanical damage. If the fruit is to be stored for a long period of time, it may be necessary to fumigate periodically to avoid insect infestation, and to sulfur occasionally to prevent undesirable color changes. In packing, apples are washed, resulfured, and then packed in boxes tightly.

(b) *Apricots, Peaches, and Nectarines*

Apricots, peaches, and nectarines are not ordinarily washed, although this is an advisable step. The fruit is cut and pitted by hand. In the case of clingstone peaches, mechanical pitters and cutters are sometimes used. Clingstone peaches should be peeled in a lye peeler prior to traying.

All of these fruits, except clingstone peaches, are placed on trays after pitting with cut surface up. The standard procedure is sulfuring the trayed fruit in standard sulfuring chambers containing the fumes of burning sulfur. Apricots should be sulfured for 3 to 4 hrs. and peaches and nectarines, for 4 to 6 hrs. The sulfuring procedure for these fruits has been described in detail by Long, Mrak, and Fisher.²¹ These fruits are ordinarily dried in the sun, whereas the peeled clingstones are dehydrated.

Sun drying results in a well-colored, translucent product acceptable to the trade. There are, however, serious objections to drying in the sun which dehydration would eliminate. When dehydrated after sulfuring, however, the apricots, freestone peaches, and nectarines are opaque and generally unattractive. To overcome this, steam blanching prior to sulfuring may be used.

Apricots may be blanched from 1 to 3 min., and peaches and nectarines from 5 to 15, depending on the size and maturity of the fruit. The blanched fruit is sulfured,

and then dehydrated. The drying time for apricots may range from 6 to 8 hrs.; for peaches, 10 to 18; and for nectarines, 8 to 10. When the countercurrent tunnel dehydrater is used, the temperature should be in the neighborhood of 150° F. Mrak *et al.*²⁴ have discussed the dehydration of these fruits.

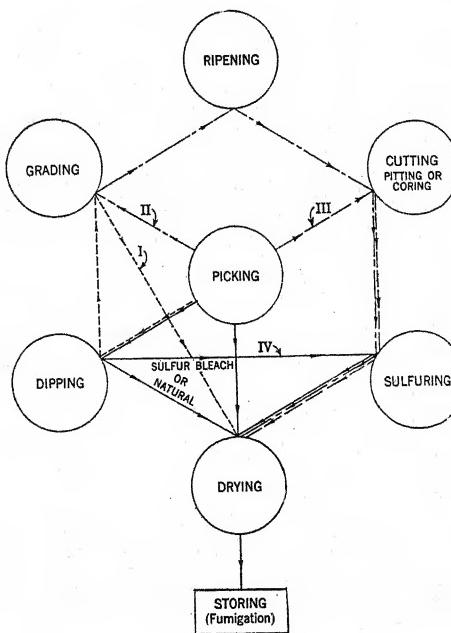


Fig. 46.—Flowsheet indicating the steps used in the drying of the more common fruits.

(c) Pears

Pears, like apples, undergo an intensive spray program during development on the trees. Even greater care must be taken in washing pears than apples, since pears are not peeled prior to drying.

In preparation, the fruit is stemmed and halved, and the pit cavity and calyx end removed. The cut fruit is trayed, cut surface upward, washed in a spray of water, and then sulfured from 24 to 48 hrs. In the production of the highest quality of dried pears, sulfuring is continued until the structure of the fruit is completely broken down, except for the skin and core.

In normal practice, the fruit is exposed to the sun for a few days, and then dried in the shade.

If pears are to be dehydrated, they should be steam blanched for 15 to 25 min. prior to sulfuring. Unblanched pears dry slowly, and are unattractive to the trade. The

dehydration temperature ranges from 150 to 160° F. in a countercurrent drier, and the fruit is dried in 24 to 28 hrs.

It is preferable to store the dried fruit in boxes, although bins are used. As in the case of other fruits, care must be taken to avoid storage infestation.

2. Whole Fruits

Several fruits are dried whole, although they are usually given some sort of pretreatment.

(a) *Prunes*

Prunes are washed, dipped in a hot lye solution, ranging in strength from 0.25 to 0.5%, until the skins show very fine checks. This is always done when the fruit is to be dried in the sun, since it facilitates sun drying, and no other pretreatment is necessary.

In dehydration, the alkali dip may be omitted, although it is necessary to wash the fruit thoroughly. The washed fruit is spread on trays and dehydration is usually accomplished in a tunnel drier. The maximum temperature seldom exceeds 165° F.; the drying time usually ranges from 18 to 24 hrs. Dried prunes are stored in bins, where an equalization of moisture content takes place.

(b) *Grapes*

Grapes may be handled in several ways. The so-called natural muscat and Thompson Seedless raisins are prepared by placing the grapes, without any pretreatment, on trays for drying in the sun. When the fruit is about half dried, it is turned. The drying requires about three weeks, after which the fruit on paper trays is rolled into "biscuits" to permit an equalization of moisture. Wooden trays containing grapes are stacked after this period of time to permit the fruit to undergo further curing in the shade. Eventually the raisins are passed over a shaker screen to remove foreign material, placed in sweat boxes, and then stored. Untreated raisins are never dehydrated.

Seedless grapes made into sulfur-bleach raisins are dipped in a hot, dilute 0.5% alkali solution for a few seconds to cause very fine checking of the skin, then washed in a spray of cold water. After this they are trayed, sulfured for about 2 hrs., and exposed to the sun for about 3 hrs. to acquire the proper bleach, then dried in the shade. Golden-Bleach raisins are handled in a very similar manner, except that after sulfuring they are dehydrated without exposure to the sun. The dehydration temperature ranges from 155 to 165° F., and the time, from 16 to 20 hrs. Tunnel dehydrators are used for this purpose.

To prepare valencia raisins, muscat grapes are also dipped in an alkali solution, but as the skins are tougher, the treatment does not check them.

(c) Figs

As stated, figs ordinarily undergo considerable drying on the trees, unless they are harvested for canning, in which case the cull-outs are dried. Those harvested for drying may be spread on trays where the curing is completed in the sun, or they may be washed and dehydrated. Figs harvested in a fresher state, such as the cull-outs from canning fruit, are commonly sulfured, exposed to the sun for 2 to 3 days until the green color has disappeared, and then dehydrated in a tunnel at about 150° F. Figs must be carefully sorted after drying to remove culs resulting from insect, microbiological, or mechanical injury. Frequent fumigation during storage is very essential for figs. Although figs may be stored in bins, it is preferable to store them in large sweat boxes.

(d) Cherries

Cherries are seldom dried under ordinary circumstances because of more profitable outlets in the fresh market and canning and freezing industries.

Sweet cherries should be dipped in 0.25% sodium carbonate solution for 5 to 10 seconds, until the skins show very fine checks. It is advisable to sulfur cherries for color and flavor retention after storage.

Since sour cherries are used primarily in the baking industries, it is advisable to pit the fruit and then sulfur it to obtain maximum color retention. Dried cherries are best stored in boxes.

(e) Berries

Most berries, except strawberries, may be dehydrated without any pretreatment except washing, at about 150 to 160° F. It is advisable to sulfur strawberries before dehydration.

Since cranberries dry very slowly if untreated, it is necessary to puncture or slice the fruit prior to drying. Considerable quantities of cranberries are at present being pureed, and dehydrated on drum driers for use in the manufacture of cranberry powder and for cranberry cocktail.

3. Procedures for Vegetables

Detailed procedures for the various vegetables are to be found in summaries by Cruess and Mackinney.²⁷ A few comments are added in the following paragraphs.

Preparation for Blanching.—Asparagus tips only should be used; similarly only artichoke hearts give a satisfactory product. Cabbage is shredded, in widths of $\frac{3}{16}$ inch. Carrots and potatoes are now preferably diced, as cans will hold more than if in strips, julienne style. Onions are sliced, with root crown and top removed. Green beans are washed and sliced, dry beans are soaked for 10 to 15 hrs., and cooked. Peas are shelled. Corn may or may not be removed from the cob. Cauli-

²⁷ W. V. Cruess and G. Mackinney, Calif. Agr. Expt. Sta., *Bull.* 680 (1943).

flower buds and Brussels sprouts are cut in half, lengthwise. Tomatoes for powder are pulped and concentrated to 20% solids. Potatoes, carrots, beets, etc., are peeled with lye,²⁸ or brine,²⁹ or by flame or abrasion peelers, or steam at 50 lbs. with mild abrasion.

Blanching.—Blanching times vary, depending on the load and rapidity of heat penetration. In general, 3 to 6 min. is adequate for leafy vegetables, 10 to 20 min. for peas, beans, and corn, and 5 to 10 min. for potatoes, carrots, and similar vegetables. The above figures assume 212° F. at sea level.

Tray Load.—Tray loads are normally from 1 to 1.5 lbs. per ft., mostly from 1 to 1.25 lbs. Cabbage, chard, and greens should not be loaded over 1 lb. per sq. ft.

Finishing Temperatures.—Although in the parallel flow, during early stages of drying, there is much variation in initial temperatures, the final finishing temperature must be more carefully controlled to prevent burning of the product. Safe finishing temperatures for most vegetables are 140 to 145° F. but 160° is permissible for cooked dried beans, 155° for carrots, 160° for corn, and 135° for onions and squash.

Final Moisture Content.—The final moisture content permitted is 5% for most vegetables and 2 to 3% for powders. Cabbage, broccoli, and similar vegetables should be dried to 4%, while 7% is permitted for potatoes.

Packaging.—Carrots and cabbage must be packed in inert gas. Carbon dioxide is normally used. The cans (5-gal.) are filled by displacement. Evacuating and releasing with inert gas is, however, far more effective; this method has been introduced in several plants.

4. Meats

The dehydration of meats is a relatively new industry, and procedures are not standardized. They are discussed by Stateler³⁰ and Kraybill.³¹

Cutter-type cattle with about 10% fat, or boneless shoulders of pork with about 20%, are used for drying. The fat is also removed to a large extent from mutton and chicken. Veal is not dried because of the soft texture of the flesh, and because of the inferior quality of the finished product.

The meat is cut into 2-in. cubes, and then is cooked in steam-jacketed kettles, without the addition of water, for 30 min. under 10 lbs. pressure, and 50 min. under 3 to 5 lbs., or until the temperature of the meat has been at 165° F. for 30 min.

Upon cooling, beef will reabsorb all the liquids surrounding the meat, but pork will not. The pork juices therefore are drained off, cooled, skimmed free of fat, and concentrated under vacuum to one-fifth the original volume. It requires about 30 minutes to produce a thick concentrate containing very little water. This concentrate is added to the pork meat after drying.

²⁸ L. C. Mazzola, *Food Industries*, 15, No. 1, 53 (1943).

²⁹ Information Sheet A-10-1, Western Regional Research Laboratory, Albany, Calif.

³⁰ E. S. Stateler, *Food Industries*, 14, No. 11, 52 (1942).

³¹ H. R. Kraybill, *Ind. Eng. Chem.*, 35, 46 (1943).

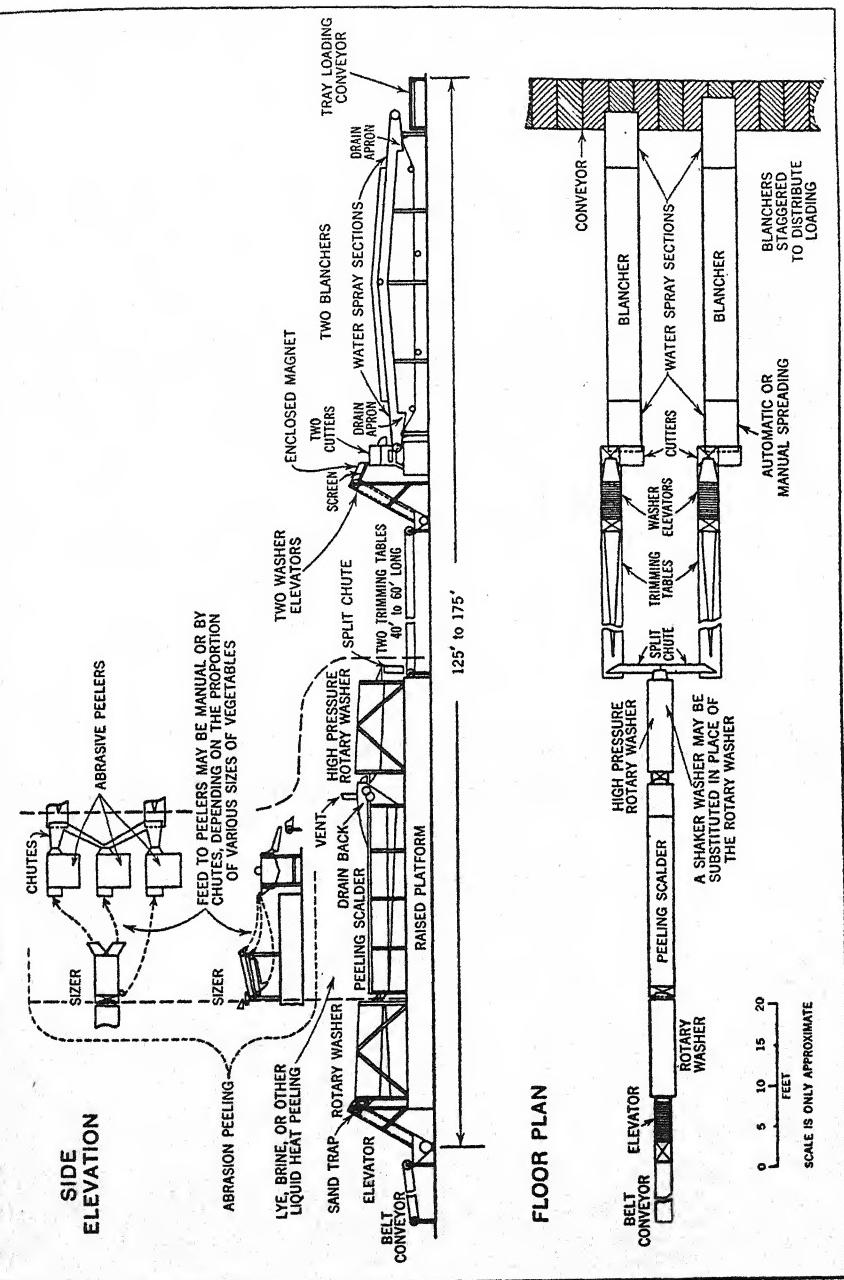


Fig. 47.—Preparation lay-out for a 100-ton vegetable dehydration plant. (Courtesy The Agricultural Research Administration.)

The cooked meat, beef with juices or pork without juices, is passed through a meat chopper at the entrance of a continuous rotary drier, where it falls onto the louvers of the drier as it leaves the hasher. Drying requires about $2\frac{1}{2}$ hrs. When the entering air temperature ranges from 300 to 315° F., the temperature at the surface of the meat is about 100° .

The moisture content of the meat at the time of entering the drier is about 50%, and when dried, about 10%, for both beef and pork.

Packaging is accomplished within 3 hrs. after drying. Pressure is used to compress the meat into cans which are sealed under a 20-in. vacuum. The dried beef is packaged without any addition, but pork juice concentrate is mixed with the dried pork flesh before packaging.

Recently, Watts³² found that the addition of about 30% of cereal such as corn meal, rolled oats, or rice to the ground meat prior to cooking will increase the storage life and improve the flavor of the reconstituted product considerably.

5. Milk

Although milk has been dried for a number of years, only recently has this product been powdered in quantity by a process yielding a product with good flavor and storage stability. The objection to drum driers lies in the danger of scorching. Drum powder is less soluble than spray powder and is used industrially in bakery products.

Jack and Henderson³³ studied the effect of various pretreatments and antioxidants on the storage stability of whole milk powder. Avenex No. 7, when added at the rate of 2 to 3% of the milk solids, or Avenol at the rate of 0.5% of milk solids, prevented the development of oxidized flavor in whole dried milk for approximately 8 months. Samples pasteurized at 142° F. for 30 min. prior to spray drying can be expected to keep satisfactorily for 2 to 6 months, with a longer keeping time resulting from the use of higher drying temperatures.

6. Eggs

The production of dried eggs has increased greatly in recent years because of the ease of shipping. Mulvany³⁴ has pointed out that great care must be taken in the cleaning of eggs prior to cracking because the bacterial count is always high when eggs from dirty shells are dried, and a certain type of bacteria can cause deterioration of the powder during storage. Egg cleaning may be accomplished by wet washes and sand blasting. Goresline³⁵ has outlined the procedure used in spray drying eggs. After cracking by hand, the eggs must be examined carefully for indications of internal defects and malodors. A single musty egg will contaminate a large batch. The liquid egg is composited from the breaking table, churned to obtain a homogeneous liquid,

³² B. M. Watts, personal communication.

³³ E. I. Jack and J. I. Henderson, *Food Industries*, 14, No. 3, 50 (1942).

³⁴ H. A. Mulvany, *Food Industries*, 13, No. 12, 50 (1941).

³⁵ H. E. Goresline, *Proc. Inst. Food Tech.*, 1943, 70.

and filtered to remove small pieces of shell and membrane. The filtered egg liquid may then be sent through pressure pumps to the drier or, if stored, held in refrigerated tanks.

The liquid is passed into a spray drier, through a spray nozzle under pressures ranging from 1800 to 5000 lbs. per sq. in. It is necessary to balance the pressure at the nozzle and size of opening against the temperature, humidity, and velocity of the air in the drier. The inlet temperatures of driers range from 230-400° F. The powder is removed from the drier, cooled to 85° or less, and packaged at about 5% moisture. Stewart, Best, and Lowe³⁶ however, have shown that whole egg powders containing less than 1% moisture have superior keeping qualities, and the trend is toward the lower moisture content. Attempts by Stewart *et al.*³⁶ to produce eggs of moisture content lower than about 3% in the spray drier itself have resulted in a product of lowered solubility, so that it may be necessary to follow spray drying with vacuum drying to produce dried whole eggs with a moisture content of about 2%.

V. RECONSTITUTION AND COOKING

The procedures used in the preparation of dried food for consumption may well result in its acceptance or refusal, regardless of the quality of the original material. Presoaking may or may not be necessary. It has been a common practice to presoak dried fruits, although the recent trend has been to recommend direct, slow cooking. The latter procedure is satisfactory for dried freestone peaches, but when used for dried clingstone peaches the volume recovery is poor.

The quantity of water required varies with the drying ratio of the product and with the quantity of material being prepared. The amount of water necessary to add increases with the drying ratio, but decreases when larger volumes are being cooked. This is well illustrated by the formulas given in the United States Army manual for preparing dehydrated foods.

The time required for cooking varies with the preparation procedure, as well as the nature of the dried material. In general, blanched materials cook much faster than when unblanched; the same may be said of young or tender materials. Particle size is important because reconstitution and cooking are more rapid when the subdivisions are smaller.

Well-prepared dried foods should be palatable and have a pleasing texture and appearance, although the rehydration ratios cannot be expected to equal the dehydration ratios, see Table 25. This may require more than proper cooking and seasoning. Milk prepared by the use of the powdered product, for example, is said to possess a superior taste if aerated and permitted to stand some hours before using. Powdered eggs should be well mixed with water in order to secure a cooked product with a fluffy texture, rather than one that is firm and hard.

The question of the fate of sulfur dioxide in dried fruits during cooking has arisen frequently. Data indicate that fruit boiled 30 to 40 min. will lose 70-80% of its sulfur

³⁶ G. F. Stewart, L. R. Best, and B. Lowe, *Proc. Inst. Food Tech.*, 1943, 77.

dioxide during this period; but, where the cooking procedure involves a slow simmer, the loss is appreciably less.

Proper training in cooking will play an important role in the fate of some of the newer dried food industries, particularly vegetables, milk, and eggs. At present most of these products, except those produced by home drying, are being utilized by the Army or for Lend-Lease purposes. Even in these cases there have been varying reports concerning their preparation.

TABLE 25
DEHYDRATION AND REHYDRATION RATIOS^a

Dehydrated item	Dehydration ratio	Rehydration ratio
Apple nuggets	10:1	1:8
Beets	10:1	1:7
Cabbage	18.5:1	1:8.50
Carrots	10:1	1:5.75
Cranberries	10:1	1:12 (sauce)
Eggs, whole .....	...	1:3.80
Milk, skim	11:1	1:10
Onions	10:1	1:6
Potatoes, julienne style	6:1	1:3.67
Potatoes, sweet	4:1	1:3
Potatoes, white, precooked, riced	6:1	1:5
Soup, pea or navy bean .....	....	1:4 (thick)
Turnips, yellow	12:1	1:6 (thin) 1:6

^a After P. P. Logan, *Canning Age*, 23, 514 (1942).

VI. NUTRITIVE VALUES OF DEHYDRATED FOODS

It is not proposed to survey here a very extensive literature on nutritive values, but certain questions will be briefly considered.

1. Is there necessarily inevitable loss inherent in the dehydration process? In general, if specific components are considered *individually*, the answer is that there need not be, but methods suitable for maximal retention of one component, such as ascorbic acid, may be less suited for retention of another, for example, thiamine. An orange juice powder has recently been prepared commercially under special conditions, in the absence of oxygen, in which no loss of ascorbic acid could be demonstrated. This, of course, is not generally the case for such an easily oxidizable compound.

2. Under what conditions are the tests to be made? Is the dehydrated food after storage for 6 months in the tropics to be compared with what it was when freshly dehydrated, or with the original fresh material, or should the comparison be made with canned food similarly stored? No simple answer is possible. The majority of fruits and vegetables, as prepared at present and so stored, would be eaten through necessity, and for no other reason, for they would not be palatable. A mistaken assumption has been made that dried foods are not perishable, and no greater fallacy exists. These foods have certain definite uses and one cannot assess their nutritive value with precision, nor is there any specific time when they must be regarded as inedible, given sufficiently acute an emergency.

3. What criteria shall be used in evaluating nutritive values? The answer here is somewhat more satisfactory. It would seem reasonable to require of a dehydrated food that it fulfill those functions expected of it when consumed in the diet as customarily prepared. Thus, a dehydrated meat should provide as satisfactory a source of protein, regardless of treatment, as well as of certain minerals and vitamins. A fruit or vegetable should provide ascorbic acid, and one or more of the following: energy, bulk, and certain other vitamins and minerals. All foods should be palatable.

With respect to major requirements, dehydrated foods may fairly be compared with the original, and losses will be confined substantially to water-soluble components which may be leached out in blanching and to those which are easily oxidizable. It must be remembered that blanching is necessary in many instances prior to freezing storage, and in canning (see page 343), so that losses in blanching for dehydration are not more severe than for other methods of food processing. Steam blanching holds such losses to a minimum.

A final factor which should be considered involves the difference in drying and rehydration ratios. Cabbage may dry 15:1 (*i. e.*, 15 lbs. fresh yield to each 1 lb. of dry), and rehydrate 1:10. As a result, a 100-g. serving of rehydrated food can contain as much ascorbic acid as 100 g. of freshly cooked. In part this is due to the fact that drying ratios are based on the fresh weight, *prepared* but not blanched. If no significant blanching loss has occurred, as is sometimes the case with water-insoluble compounds such as carotene, there may even be an apparent increase in the dehydrated over the fresh.

It will be seen, therefore, that nutritive factors are intimately connected with storage conditions, that it is in the labile components (carotene and ascorbic acid, sensitive to oxidation; riboflavin, unstable to light; thiamine, destroyed by sulfur dioxide) that differences become most pronounced. Little progress can be made while dehydrated foods are considered nonperishable and storage conditions are ignored. The beneficial effect of low moisture on ascorbic acid in vegetables is to be noted in the work of Chace.³⁷ Retention of this factor in fruits when dehydrated is greatly superior to that in the slower sun drying methods. See Mrak *et al.*³⁸ Blanching losses have recently been reviewed by Tressler, Moyer, and Wheeler;³⁹ and numerous papers on vitamin retention in fruits have come from the laboratory of A. F. Morgan.⁴⁰ Hauge and Zscheile⁴¹ have shown excellent retention of vitamin A in eggs during spray drying.

VII. STORAGE

A number of considerations affecting storage are more or less common to all dried foods. Whether the products are offered for consumption as they come from the de-

³⁷ E. M. Chace, *Proc. Inst. Food Tech.*, 1942, 70.

³⁸ E. M. Mrak, H. J. Phaff, C. D. Fisher, and G. Mackinney, *Food Industries*, 15, No. 4, 59 (1943).

³⁹ D. K. Tressler, J. C. Moyer, and K. A. Wheeler, *Am. J. Pub. Health*, 53, 975 (1943).

⁴⁰ A. F. Morgan, *J. Biol. Chem.*, 88, 9 (1930); *J. Agr. Research*, 46, 841 (1931); *J. Nutrition*, 6, 83 (1933).

⁴¹ S. M. Hauge and F. P. Zscheile, *Science*, 96, 536 (1942).

hydrater, or are first stored in bulk and then subjected to a processing treatment, it is necessary to protect them against damage that may result from chemical reactions, insect infestation, or the growth of microorganisms.

1. Bin Storage

Most dried fruits are stored in bulk, the notable exception being raisins which are held in sweat boxes containing approximately 100 lbs. Dried vegetables, meats, milk, and eggs are packaged immediately after drying, and never stored in the exposed condition.

Bulk, or bin storage, offers the advantages of saving in space and of ease of handling. There are, however, several disadvantages. The surface of the bins is usually exposed to the open air, and hence to contamination with air-borne foreign materials and to insect infestation. The latter is a serious problem in all dried fruit packing houses. To minimize infestation, it is necessary to maintain a clean plant, and eliminate all breeding places for insects. See pages 244 *et seq.* The use of mineral oil barriers on the floor surrounding the bins and of pyrethrum air sprays may be found helpful. Even though these measures be taken, it is usually necessary to fumigate periodically with methyl bromide or some other effective fumigant.⁴²

If unsulfured fruits stored in bins are not low in moisture, incipient microbiological deterioration may take place, most commonly in figs and prunes. It is caused by sugar-tolerant yeasts which, in spite of slow growth, cause noticeable changes in taste and appearance. This type of deterioration can be eliminated either by aeration or by binning only fruit of low moisture content.

When these fruits are stored in boxes, drying out of the fruit is likely to be more rapid, so that yeast spoilage is reduced. This type of spoilage seldom occurs in sulfured fruits even though binned.

Large bins may contain as much as 40 tons of fruit; considerable pressure is exerted on the fruit in the lower layers. This may cause considerable mechanical damage which can be avoided by use of smaller bins or sweat boxes.

2. Storage in Packages

The preferable procedure for handling dried foods is to package immediately after drying. Although storage in containers is space consuming, it offers the advantages of cleanliness, protection against insects, and when tin containers are used, prevention of the absorption of moisture. Most substitute containers are fiberboard, or fiberboard with metal-foil laminated bags. Although these containers are substantially moistureproof, Essig⁴³ has recently shown that certain storage insects are capable of entering most of them. There are insects that can penetrate lead foil and asphalt-laminated containers. See pages 246 *et seq.*

⁴² W. M. Mrak and J. D. Long, Calif. Agr. Expt. Sta., *Circ.* 350 (1941).

⁴³ E. O. Essig, personal communication.

Cleanliness is important in controlling storage infestation in these containers, since insects penetrate fiberboard cartons more rapidly when slight quantities of food material are on or near the carton. Even though but one type of insect may enter a carton, once an opening is made other insects may follow and the package is no longer moistureproof. For these reasons fiberboard packages containing foods must be stored in places free from fragments of food material and other debris. Microbiological spoilage is not a problem in foods handled in this manner unless the carton has been penetrated and the food exposed to the outside air. In such cases it may be necessary, even under these conditions, for considerable moisture to be absorbed before micro-organisms can grow.

VIII. BIOCHEMICAL DETERIORATION

This type of spoilage is least amenable to control. Countermeasures depend upon the product, but in most cases include the lowest practicable moisture content, low temperature storage, exclusion of air, and the use of antioxidants and sulfur dioxide or sulfites. Where the product has been blanched, enzymes can be eliminated as a source of difficulty, and other causes must be sought.

Deterioration in meats is usually due to rancidity of the fat, but protein hydrolysis can occur, as in wheat germ.⁴⁴ Rancidity in meats may be greatly delayed by admixtures of corn, wheat, or oatmeal preparations. Gum guaiac has also been advocated.⁴⁵

Broadly speaking, dried fruits deteriorate by a process akin to caramelization, whereas vegetables develop off-flavors and odors resembling rancidification in certain respects. In carrots, for example, which develop haylike odors, a positive Schiff test can be developed, indicative of aldehydes. The low lipid content makes it difficult to determine a peroxide number with accuracy, but small differences have been noted on prolonged storage. Deterioration in carrots and cabbage can be held in check by the judicious use of sulfite solutions,⁴⁶ applied as sprays or dips prior to dehydration. However, unless the moisture content of the dried product has been lowered to the lowest practical limit, the effect of the sulfite may easily be nullified. The protective action of the added sulfite in vegetables appears, on the basis of present information, to be due to its effectiveness as an antioxidant. In this rather broad generalization on deterioration of vegetables on storage, it should not be overlooked that caramelization or browning may be shown if the storage temperature is too high, above 90° F. for any extended time. Unsulfited potatoes will become progressively more amber at 100° or over. At lower temperatures, carrots tend merely to bleach unless sulfited, and caramelization is not appreciable below 100°.

The best illustration of the darkening process is found in the sulfured dried apricot stored for 2 or 3 weeks at temperatures of 100–120° F. The sulfur dioxide content falls

⁴⁴ J. A. Pearce, *Can. J. Research*, C21, 57 (1943).

⁴⁵ H. S. Mitchell and H. C. Black, *Ind. Eng. Chem.*, 35, 50 (1943).

⁴⁶ G. Mackinney in *Dehydration Manual, Western Canner and Packer*, San Francisco, 1943.

steadily and the fruit soon becomes black. Some confusion has been caused by failure to recognize at least three types of darkening in fruits. There are two types of oxidative spoilage dependent upon the presence of plant oxidases and their substrates, and upon the breakdown of autoxidizable substances. The type under consideration here is apparently not oxidative in character, and is certainly not dependent upon molecular oxygen, which can be very completely removed from a container with hydrosulfite. Furthermore, such easily oxidizable compounds as carotene can be demonstrated in a black apricot. This type of deterioration has certain peculiar characteristics. Above a certain maximum moisture content, about 30%, it does not occur at a measurable rate. There is also some indication that it can be held in check at moisture contents below 1%. There is normally no development of haylike odors, although there is marked loss in palatability. The darkening involves the carbohydrates,^{47, 48} and specifically fructose. A homogeneous fraction, the so-called "dark compound"⁴⁷ constitutes 5-9% of the total apricot. It contains nitrogen which is only identifiable in the humin fraction. The phenomenon should be clearly differentiated from discolorations resulting from oxidation of tannins and other phenolic compounds, or of ascorbic acid, whether natural or artificially induced.

On storage, there is continuous production of carbon dioxide from the apricot, even at 5% moisture.⁴⁹ This is not greatly affected by the moisture content, in the range tested (5-25%), but is of course accelerated with temperature. In air, there is rapid oxygen consumption at 20% moisture which is greatly diminished at 5% moisture. Consequently, storage in inert gas is relatively ineffective, and at 120° F. storage may even be slightly deleterious. There is an odd Pasteur-like effect obtained with apricots above 100° F. storage, a greater production of carbon dioxide under anaerobic conditions, than when stored in air. The darkening has been correlated with carbon dioxide production.

Fruits offer many difficulties, largely because they are normally not dehydrated and promptly packaged under ideal conditions. Even dehydrated prunes are mixed with sun-dried batches, and as a result, for sanitary reasons, most fruits must be processed, which involves washing and resulfuring. Because of lack of control in the original sulfuring and uncertainty in sun drying, much of the subsequent susceptibility to spoilage may be irremediable. Under peacetime conditions, the fruit is stored in bins until loss in color is sufficiently marked so that the packer is forced to wash and resulfur his fruit, and to sell the product in temperate zones where it will not darken too rapidly.

Much effort has been directed toward determining the fate of the sulfur dioxide added to fruits and vegetables. There is some indication that, in cabbage, loss of sulfur dioxide is paralleled by a gain in sulfate. This is in keeping with the view that the sulfur dioxide is acting here as an antioxidant. In the more highly acid fruit, the increase in sulfate varies from 0 to possibly 40% of the sulfur dioxide lost. Several

⁴⁷ C. A. Weast and G. Mackinney, *Ind. Eng. Chem.*, **33**, 1408 (1941).

⁴⁸ W. E. Isaac, *Ind. Eng. Chem.*, **35**, 470 (1943).

⁴⁹ H. A. Barker and E. Stadtman, personal communication.

workers have noted that the total sulfur content of the apricot remains constant. In view of the parallelism between loss of sulfur dioxide and darkening of the tissue, which is virtually unaffected by molecular oxygen, the possibilities of dismutation have been considered. It is also possible that the sulfur dioxide behaves as an oxidizing agent, and that some undetected component of the fruit has undergone oxidation. The sulfur dioxide appears to delay deterioration in the fruit by virtue of its power to form addition compounds. These include aldohexoses, amino acids, and quinones such as vitamin K. Whether or not this hypothesis proves to be correct, progress requires clear-cut proof of the role played by sulfur dioxide added to fruits and vegetables, so that better treatments can be intelligently planned.

IX. CURRENT RESEARCH AIMS

The improvement of palatability under unfavorable storage conditions imposed by wartime necessity is still a primary objective. In general, palatability and retention of nutritive value are closely associated. The sulfiting of carrots and cabbage has received serious consideration, not because of free choice, but because these vegetables stored under tropical conditions for a few months will be inedible unless so treated. An added incentive is that retention may be greater than in the unsulfited control.

The possibility of substitutes for sulfur is under continuous examination. An important step forward will have been achieved when the fate of the added sulfur dioxide has been worked out.

The importance of better packaging should not be underestimated. Packages must be insect- and moistureproof, and preferably impermeable to gases or other vapors. Compression studies are also of great importance.

The future of the dehydration industry depends, not on the engineering problems imposed by temporary restrictions, but upon producing a palatable product indistinguishable from the freshly prepared food. Much information on the best methods for reconstitution is still needed.

Insofar as a central thesis has been established, it is that dehydrated products must be considered in relation to storage because success or failure in storage determines palatability, and whether or not the product will find acceptance.

Chapter X

FOOD PRESERVATION BY TEMPERATURE CONTROL

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The principal causes of food spoilage are the growth of microorganisms, chiefly bacteria, yeasts, and molds, the action of enzymes which occur naturally in the foods, chemical reactions such as oxidation and hydrolysis, and desiccation. The last is often a cause of deterioration of many foods, e. g., fruits, vegetables, and baked goods, but it does not affect all kind of foods.

Cool storage materially reduces the rate at which foods deteriorate from all four of these causes. Bacteria, yeasts, and molds grow much less rapidly near 32° F. than at ordinary room temperatures. Most enzymes are still active at 32° F., but the rate at which they act is far below that at 70°. Similarly, the oxidation and hydrolysis of foods occur relatively slowly at cool storage temperatures. Water evaporates less rapidly at low temperatures than at high, and consequently the rate of food spoilage because of desiccation is markedly reduced by refrigeration.

Storage at temperatures below freezing is even more effective in reducing deterioration. However, freezing itself causes marked changes in many foods and is the accidental cause of spoilage of some fresh foods, such as fruits and vegetables.

If foods are refrigerated at temperatures below 15° F., spoilage by microorganisms is entirely prevented, since growth of yeasts and molds does not occur, and bacteria multiply so slowly that foods are not affected. Much lower temperatures are required to prevent deterioration by desiccation or enzymic and chemical actions. The temperature of the storage must be reduced to -40° F. or even lower in order to reduce enzymic and chemical changes to insignificance. Desiccation and oxidation are best prevented by proper packaging of foods prior to freezing. In the case of certain vegetables and some other foods, enzymic action is stopped by precooking prior to storage.

In general, then, it can be said that refrigeration at the temperatures of commercial cold storages does not stop the deterioration of perishable foods; it merely retards it. Further, as a rule, the lower the temperature the slower the deterioration. However, there are many exceptions to the latter statement, as some foods are damaged by reducing the temperature too far. These notable exceptions will be mentioned later.

I. PRINCIPLES OF MECHANICAL REFRIGERATION

1. The Compression System

When a liquid (or refrigerant) evaporates it absorbs heat and thereby cools its surroundings. See page 70. Upon this principle ordinary mechanical refrigeration is based. In actual use, the liquid is allowed to evaporate in coils or plates (evaporators), and the gas which is formed is drawn off and compressed. Compression warms the gas; so it passes to a condenser where it is cooled either by running water or by air from a fan. Cooling causes the compressed gas to liquefy. The liquid refrigerant is collected in a receiver from which it again passes through an expansion valve into the refrigerating coils or plates, thus completing the cycle.

A relatively high pressure is maintained from the compressor to the condenser and in the receiver up to the expansion valve. Consequently this side of the system is known as the high side or high-pressure side. Because the pressure is low from the expansion valve, through the refrigeration coils (evaporators) up to the compressor, this is known as the low side or low-pressure side.

There are two types of methods of feeding refrigerant to the evaporator: the conventional expansion valve type, and the flooded system. Expansion valves may be hand-controlled, pressure actuated, or thermostatically controlled. In the flooded system, the refrigerant is usually fed to a surge drum or trap located above the evaporator and in which a definite level of liquid refrigerant is maintained by means of a float valve working on the ball-float principle. Liquid refrigerant is fed by gravity from this surge drum to the refrigeration coils or plates and the amount of refrigerant fed is dependent directly upon its rate of evaporation.

2. The Absorption System

In a refrigeration machine designed according to the absorption system, the increase in pressure is obtained by means of heat applied to aqua ammonia in the generator instead of by a compressor as in the compression system. The warm ammonia is cooled and liquefied in a condenser (just as in the compression system). The liquid ammonia is fed through an expansion valve to the evaporator, where it vaporizes and absorbs heat. The gas returning from the expansion coils enters the absorber (corresponding to the suction end of the compressor), where it is absorbed in weak ammonia liquor cooled by cold water coils. From the absorber, the aqua ammonia is pumped to the generator, where it is again heated, thus completing the cycle. After the aqua ammonia has given up most of its gas, it passes again to the absorber, where it is cooled and reabsorbs ammonia coming from the evaporator coils.

3. Refrigerants

Ammonia is commonly used as the refrigerant (see page 82) in most large cold storage warehouse and freezer installations. Fluorinated hydrocarbons, such as dichlorodifluoromethane commonly known as Freon-12, and similar compounds, are

being used in many of the smaller commercial installations. Carbon dioxide is sometimes used on shipboard and where extraordinarily low temperatures are required. Sulfur dioxide is the common refrigerant in household refrigerators. Methyl chloride, methylene chloride, and ethyl chloride are employed in some small commercial units and a few makes of household refrigerators.

4. Cold Storage Warehouses

Cold storage warehouses are insulated buildings divided up into a number of different rooms, each of which is also insulated. The rooms are cooled by allowing a refrigerant, usually ammonia, to evaporate in coils. Usually the coils are hung overhead, although they may be placed along the walls.

Some warehouses use expansion coils to cool large tanks of calcium chloride brine, and then circulate this brine through coils in the rooms to be refrigerated. The brine should be neutral or slightly alkaline or else it will be very corrosive.

There are two general types of warehouse construction, the "curtain wall" and the "insulated," although both are really insulated. The curtain wall has an outer and an inner shell, the outer shell being of common building material and the inner of insulating material. The outer walls are carried up independently of the rest of the building.

II. COOL STORAGE OF FOODS

1. Meats

Fresh meats are highly perishable, and therefore must be cooled immediately after slaughter and kept just above the freezing point until used. *Veal* is especially perishable and cannot be stored long even if the temperature is maintained at 32° F. *Pork*, *lamb*, and *mutton* do not spoil so easily but still are difficult to keep for more than a week or two. *Beef* keeps somewhat better, but even so 6 weeks is about the limit. *Glandular organs*, such as *liver*, *kidneys*, *brains*, and *heart*, soon spoil even at 32°, and so should either be sold promptly, or else frozen and stored at 0°.

During the chilling process, from 1.5 to 2.5% of moisture is lost from the carcass. Air circulation is important in order to obtain rapid chilling of the meat. If inadequate refrigeration is applied, the meat may sour around the bone. If the humidity in the chill room is low, the chilling shrink will be excessive; for this reason the humidity should be maintained well above 90%.

After the temperature of the meat has been reduced to about 32° F., it should be moved into a storage maintained at a uniform temperature of 31 to 33°. Temperatures as high as 35 to 37° are unsatisfactory, because microorganisms grow too rapidly and will cause surface spoilage. If the relative humidity is above 90%, the meat will mold and slime will develop. A relative humidity below 90% permits excessive desiccation and consequent loss of bloom. Air movement helps to prevent mold growth, but should be gentle, as otherwise excessive desiccation will occur.

In small packing establishments, one room sometimes is used both for chilling and storing the chilled meat. Such a situation is undesirable because there is too much fluctuation of temperatures as a result of bringing in warm meat to have satisfactory storage conditions. Furthermore, if a sufficiently high humidity is maintained in order to prevent great shrinkage of weight during cooling, the stored meat will mold and become slimy.

Aging tenders meat somewhat. Since pork, lamb, and veal are always sufficiently tender, they are not aged by storage. Most packing-house beef is sold within 5 to 10 days after slaughter. Some large users of meat, e. g., hotels, hold their beef at 32° F. for several weeks in order to tender it. During this process, some mold may grow on the surface, and is trimmed off before the meat is used.

Recently, a novel method of rapidly aging meat called the "Tender-Ray" process has been introduced. Special lights, germicidal or "steril" lamps, are employed to maintain aseptic conditions in the cool storage room. These lamps give off a high percentage of ultraviolet light, which possesses germicidal power. If all of the surface of the meat is exposed to these germicidal lights at all times, it will not spoil quickly because of the growth of microorganisms even though the temperature is high enough to permit rapid enzyme action.

2. Preserved Meats

Ham, bacon, smoked sausage, salted pork, corned beef, etc., are much less perishable than the corresponding products before curing. Nevertheless, they should be held under refrigeration if they are to be kept for longer than a few days. Although these products will keep for weeks at 40° F., temperatures of 30° to 32° are preferable. During storage, pork fat tends to turn rancid because of oxidation. The development of rancidity is retarded by refrigeration; the lower the temperature the more slowly rancidity develops.

3. Fish

Fresh fish is even more perishable than meat. Storage, even at 32° F., causes the fish flesh to become undesirably soft. Further, the bright color of the skin of the fish soon turns dull. The characteristic flavor of fresh fish is first lost, unpleasant strong flavors develop, and the product soon becomes inedible. Staling and subsequent spoilage of fish are caused both by the action of enzymes and the growth of microorganisms.

During transportation and storage awaiting sale, fish are usually packed in finely crushed ice or "Flak-Ice." If either coarse or chunk ice is employed, the fish will be bruised by it and will consequently deteriorate rapidly. See Volume I, page 499.

When caught at sea, the fish are packed with crushed ice in bins which keep the fish from sliding around as the ship rolls. Usually no auxiliary refrigeration is employed. When the fish are unloaded, they are packed with crushed ice in heavy wooden boxes.

The proportion of ice to fish employed depends upon the probable length of time which will elapse before the fish are to be used and the temperature to which they will be exposed. The boxes of iced fish are either shipped or are placed in cool storage (32-35° F.) until required for shipment or sale. The length of time that iced fish can be stored without actual spoilage depends upon the species of the fish and the condition of the fish at the time of icing. Soft fish, such as whiting, will not keep long under any circumstances. Under optimum conditions, firmer fish, e. g., cod, may be kept for 3 weeks.

4. Preserved Fish

Although salting and smoking are fairly effective in preventing the spoilage of fish because of the growth of microorganisms, these methods of preservation do not stop the oxidation of the highly unsaturated fats of these products and the consequent development of rancidity. If these foods are to be kept for longer than a week or two, they should be maintained at low temperatures, preferably 10 to 15° F. Because of the low moisture content of salted and smoked fish, freezing does not cause damage.

5. Shellfish

Live oysters and *clams* can be kept in cool storage for a week or two provided the temperature is maintained just above the freezing point. *Shucked oysters*, *clams*, and *scallops* are somewhat more perishable. Ordinarily these products are stored only for 3 to 4 days while awaiting sale. They are best sealed in tin cans immediately after shucking. The cans of shellfish are then packed with crushed ice in larger containers which are either shipped immediately or are placed temporarily in a cool room maintained at 32° F.

Green and cooked shrimp, *cooked lobster meat*, *spiny lobster tails*, and *cooked crab meat* are all very perishable and can be kept in storage even at 32° F. for a few days only.

6. Fruits and Vegetables

Fruits and vegetables are alive and consequently respire, that is, they take up oxygen and give off carbon dioxide. For this reason they must be neither packed in air-tight containers nor permitted to freeze. It must also be remembered that they are easily damaged by freezing.

The best temperature for the storage of most fresh fruits and vegetables is 32° F. The lower the temperature, the less the physiological activity of any fruit or vegetable. Furthermore, the lower the temperature, the less danger of spoilage because of the action of microorganisms. However, certain fruits and vegetables do not tolerate well temperatures near the freezing point. *Bananas*, *lemons*, *grapefruit*, *cucumbers*, *tomatoes*, *potatoes*, *avocados*, *melons*, and *pineapple* are included in this group. The optimum storage temperatures for these products are given in Table 26. The tempera-

tures given are optimum for long storage. If fruits and vegetables are to be stored for short periods, higher temperatures can often be used satisfactorily.

Because of the fact that fruits and vegetables contain a high percentage of water, a relatively high humidity should be maintained in the storage room, or the products will lose weight rapidly because of evaporation of the moisture, and eventually will wilt. Loss in weight is greater in leafy vegetables than in root crops or fruit. Optimum humidity conditions for fruits and vegetables are indicated in Table 26 also. (See page 318.)

Special precautions should be taken in storing *apples*, *bananas*, *grapefruit*, *grapes*, *lemons*, *melons*, *celery*, *cucumbers*, *eggplant*, *sweet potatoes*, *onions*, *pears*, *potatoes*, *pumpkins*, *squash* and *tomatoes*. Much valuable information concerning cool storage of fresh fruits and vegetables is presented in the *Refrigerating Data Book* and the publications of the United States Bureau of Plant Industry.

(a) Gas Storage

Recently, it has been found that *apples*, *pears*, and certain other fruits will keep much better under refrigeration if held in an atmosphere containing a considerable amount of carbon dioxide. The use of atmospheres containing carbon dioxide is known as gas storage. The amount of carbon dioxide needed to obtain optimum storage conditions varies with both the kind and variety of fruit. Gas storage increases the storage life of the fruit by reducing the physiological activity or respiration rate of the product.

Gas storage may be effected in two ways: by introducing and maintaining a definite concentration of carbon dioxide in a refrigerated gastight chamber, or by placing the fruit in containers which are gastight except for small openings of uniform size. In the latter case, the carbon dioxide is formed by the respiration of the fruit itself. The containers of fruit must of course be stored in a refrigerated room.

(b) Canned and Dried Fruits and Vegetables

Both canned and dried (and dehydrated) fruits and vegetables keep far better under refrigeration than they do at ordinary temperatures. Canned fruits must be kept in a dry place at relatively low humidities otherwise the cans will rust, and, if the cans have been labeled, the labels will fall off. Canned vegetables should not be stored below 32° F. or they may freeze and the cans will burst because of the expansion of the ice. Canned fruits contain considerable amounts of sugar, and so are safe down to a temperature of approximately 25°.

Dried and dehydrated fruits and vegetables deteriorate rapidly at temperatures much above 70°. Even at this temperature the loss in quality is easily noticeable in a few months. Refrigeration is advisable if they are to be kept longer than a month or two. The lower the temperature, and also the humidity, the better dehydrated products will keep. Because of their low moisture content, freezing does not damage them.

TABLE 26
STORAGE PROPERTIES OF FOODS^a

Commodity	Storage temp., ° F.	Relative humidity, %	Approx. storage life	Water content, %	Av. freezing point, ° F.
Apples	31-32	85-88		84.1	28.4
Artichokes					
Globe				83.7	29.1
Jerusalem	31-32	90-95		79.5	27.5
Asparagus	32	85-90	2- 5 months	93.0	29.8
Avocados	40-55	85-90	3- 4 weeks	..	27.2
Bananas	^b	^b		74.8	
Beans					
Green or snap	32-40	85-90	3- 4 weeks	88.9	29.7
Lima	32-40	85-90	3- 4 weeks	66.5	30.1
Beets					
Topped	32-35	90-95	3- 6 months	87.6	26.9
Bunch	32	85-90	7-10 days	..	
Blackberries	31-32	80-85	7-10 days	85.3	28.9
Broccoli, Ital.	32	85-90	10-12 days	89.9	29.2
Cabbage	32	90-95	3- 4 months	92.4	31.2
Carrots					
Topped	32	95-98	2- 4 months	88.2	29.6
Bunch	32	90-95	7-10 days	..	
Cauliflower	32	85-90	2- 3 weeks	91.7	30.1
Celery	31-32	95-98	2- 4 months	93.7	29.7
Cherries	31-32	80-85	10-14 days	83.0	
Coconuts	32-35	80-85	1- 2 months	milk, 95.2 flesh, 46.3	30.4 25.5
Corn, sweet	31-32	85-90		73.9	29.0
Cranberries	36-40	90-95	1- 3 months	87.4	27.3
Cucumbers	45-50	85-90	6- 8 days	96.1	30.5
Dried fruits	32-50	70-75	1- 2 years	..	
Eggplant	45-50	85-90	10 days	92.7	30.4
Endive	32	90-95	2- 3 weeks	93.3	30.9
Garlic	32	70-75	5- 6 months	74.2	25.4
Grapefruit		85-90	8-10 weeks	88.8	28.4
Grapes					
European type	31-32	80-85	4- 6 months	81.6	24.9
American type	31-32	80-85	8-14 weeks	81.9	27.5
Horse-radish	32	90-95	4- 6 months	73.4	26.4
Leeks	32	85-90	1- 3 months	88.2	29.2
Lemons	55-58	80-85	2 weeks-4 months	89.3	28.1
Lettuce	32	90-95	2- 3 weeks	94.8	31.2
Limes	45-48	85-90	7- 8 weeks	..	29.3
Melons					
Watermelons	35-40	80-85	1- 3 weeks	92.1	28.8
Muskmelons	50-55	80-85	1- 3 weeks	92.8	28.5
Honeydew—					
Honey ball	40-50	80-85	3- 4 weeks	..	28.8
Casaba and					
Persian	35-40	80-85	4- 6 weeks	..	..
Mushrooms, cultiv.	32-35	80-85	2- 3 days	..	30.2
Nuts	32-70	65-70	8-12 months	pecans, 3.2 Eng. walnuts, 2.5	^b
Onions and onion sets	32	70-75	5- 6 months	87.5	30.1
Oranges	34	80-85	1- 2 months	87.2	
Parsnips	32-34	90-95	2- 4 months	78.6	28.9
Peaches	31-32	85-90	2- 4 weeks	86.9	29.4
Pears	30-32	85-90		82.7	^b

TABLE 26 (*Continued*)
STORAGE PROPERTIES OF FOODS^a

Commodity	Storage temp., ° F.	Relative humidity, %	Approx. storage life	Water content, %	Av. freezing point, ° F.
Peas, green	32	85-90	1- 3 weeks	74.3	30.0
Peppers					
Sweet	32	85-90	4- 6 weeks	92.4	30.1
Chili, dry	32-50	70-75	5- 9 months		
Pineapple					
Mature green	50-60	85-90	3- 4 weeks	..	29.1
Ripe	40-45	85-90	2- 4 weeks	..	29.9
Plums	31-32	85-90	1- 2 weeks	85.7	28.0
Potatoes	36-60	85-90		77.8	28.9
Pumpkins	55-60	70-75	2- 6 months	90.5	30.2
Quinces	31-32	80-85	3- 4 months	85.3	28.1
Raspberries					
Black	31-32	80-85	7-10 days	80.7	28.8
Red	31-32	80-85	7-10 days	83.4	30.4
Rhubarb	32	90-95	2- 3 weeks	94.9	28.4
Squash, winter	55-60	70-75	2- 6 months	90.4	29.3
Strawberries	31-32	80-85	7-10 days	90.0	29.9
Sweet potatoes	50-55	80-90	4- 6 months	68.5	28.4
Tomatoes					
Ripe	50-55	80-85	7-10 days	94.1	30.4
Mature green	55-70	80-85	1- 6 weeks	94.7	30.4
Turnips (including rutabagas)	32	95-98	2- 4 months	90.9	30.5

^a From D. H. Rose, R. C. Wright, and T. M. Whiteman, U. S. Dept. Agr., *Circ. 278* (1933).

For bananas: green, flesh—30.2° F., peel—29.8°; ripe, flesh—26.0°, peel—29.4°. For cherries: eastern, sour—28.0°, sweet—24.7°; California, sweet—24.2°. For oranges: flesh—28.0°, peel—27.4°. For pears: Bartlett—28.5°, Winter Nellis—27.3°, Anjou—26.9°. For Persian (English) walnuts—20.0°, pecans—19.6°, and chestnuts (Italian)—23.8°.

7. Dairy Products

(a) Milk and Cream

Milk and cream are excellent media for the growth of many types of bacteria and other microorganisms; consequently they must be kept under refrigeration at all times. Freshly drawn milk is not free from bacteria, the number present normally varying from a few hundred to a few thousand per milliliter. The bacteria, which are present in milk when it is drawn, or those which enter it thereafter, develop at a rate dependent on the temperature at which the milk is held and the types of organism present. Milk low in bacteria (for example, Grade A or certified milk) will keep for about 10 days at 32° F. But at some seasons of the year such milk may become oxidized in less time. At higher temperatures of refrigeration, the permissible storage time is much shorter. Because milk is at body temperature as it comes from the cow and warm milk deteriorates very rapidly as a result of the growth of microorganisms, it is imperative that milk be cooled to a temperature below 50° immediately after drawing from the cow. Prompt refrigeration not only retards chemical changes in the milk but also reduces to a minimum the growth of any pathogenic microorganisms

which it may contain. Furthermore, milk should be kept cool until it is consumed, except of course during the pasteurization process. Immediately after this procedure, it should be cooled to a temperature close to 32°.

Modern dairies are equipped with special refrigeration units called milk coolers through which the milk is run before it is put into cans for temporary storage awaiting transportation to market. Other dairies employ spring or deep well water, or crushed ice, for cooling. If the cream is separated in a centrifuge on the dairy farm, this should be done promptly after milking; then both the cream and the skim milk should be cooled to 50° F. or below.

Pasteurization.—Immediately upon receipt at the bottling plant, the milk should be pasteurized in order to reduce its bacterial content and destroy all pathogens. *Holding pasteurization* is commonly used commercially, although a quick treatment at more elevated temperatures (high-temperature, short-time pasteurization) is employed by some dairy companies. The holding method may be carried out in vat, pocket, continuous flow, or in-the-bottle pasteurizers. Essentially, it consists in heating milk to 142 to 145° F. and maintaining the pasteurizing temperature for a period of at least 30 minutes, followed by rapid cooling to 50° or lower. *High-temperature, short-time pasteurization* is carried out by rapidly heating milk to a temperature of 160° F. or higher, holding it at that temperature for a very short time (usually 15 to 30 seconds) and then cooling it quickly to 50° or lower. Steam, hot water, or electricity may be used to heat the milk. Steam under pressure is not very satisfactory as the milk solids tend to stick to the metal of the pasteurizer and "burn on," causing poor heat transfer and a cooked flavor in the milk because of the scorched coating of milk on the metal. The use of steam at reduced pressure, of hot water or of electricity eliminates these difficulties. Milk treated by the electric method of flash pasteurization is first pumped through a regenerative heater-cooler which raises the temperature of the raw milk to 120° and reduces that of the hot pasteurized milk to the same point. The warmed milk then passes through a rectangular heating chamber, two opposite sides of which are electrodes about 3 or 4 inches apart. The other two sides are of glass or hard rubber. As the warm milk passes through this chamber it is heated to 161 to 162° by a 60-cycle alternating current. The hot milk is held at this temperature for 15 seconds, and then passes first through the heat exchanger, which as has been previously stated cools it to 120°, and then through a cooler which refrigerates it to 50° or below.

Cream should be pasteurized and refrigerated by the same methods employed for milk. However, cream to be frozen should be pasteurized at a relatively high temperature.

(b) Butter

Ordinary cool storage temperatures (*e. g.*, 32–40° F.) will do for the temporary storage of butter; but if it is to be held longer than a few weeks it should be stored at 0° F. or preferably lower.

(c) Cheese

Swiss and Roquefort cheese are best held at 38 to 40° F. Other kinds will keep longer at 31 to 32°.

8. Eggs

Eggs may be kept in good condition for 9 months or longer if maintained under the proper conditions of temperature, humidity, and air movement. The optimum storage temperature is 31° F. A very slight fluctuation of temperature is permissible in egg storages. Gentle air circulation aids in maintaining uniformity of temperature. Strips of wood are placed on the floor and between each layer of egg cases, thus permitting air circulation around the cases. High humidity is desirable because it reduces the rate of evaporation and the consequent enlargement of the air space of the egg. If the humidity is above 85%, some fungicide should be employed in order to reduce the danger of molding. A few parts per million of ozone is often maintained in the atmosphere of the room. Humidity above 90% is seldom used because of the great danger of spoilage by molding. Eggs are often oiled or otherwise treated in order to make the shells less pervious to moisture and consequently reduce the rate of evaporation.

9. Nuts and Other Miscellaneous Foods

Dried nuts and nut meats should be kept at 32° F. or below to prevent both the development of rancidity and desiccation. Chocolate candies are best held at 45 to 50°. Compressed yeast keeps best at a temperature just above freezing.

10. Wine

Dry wines will deteriorate rapidly unless held under refrigeration. During manufacture they should be chilled below household refrigerator temperatures so as to precipitate a large part of the tartrates (argols) and thus eliminate the danger of clouding during chilling at some later time, for instance, just prior to serving. Furthermore, dry wines must be kept cool at all times to prevent deterioration because of the growth of mycoderma and oxidation. Dry wines stored in casks or barrels should be held at a temperature not higher than 50° F., or mycoderma will grow and turn the wine acetic.

Dry wine is sometimes stabilized by pasteurization after bottling, or by flash heating just prior to bottling. A temperature of 140° F. effects sterilization.

Bottled wine must not be stored at a temperature lower than that at which it has been chillproofed; otherwise it may cloud. Although sweet wines do not necessarily have to be kept under refrigeration, they may cloud if stored at temperatures much above 70° F.

III. FREEZING PRESERVATION OF FOODS

Storage of perishable foods at temperatures above freezing is ordinarily employed to keep them for relatively short periods—a week or two in the case of fish, one to six

weeks for meat, and for a maximum period of a year in the case of gas-stored apples. On the other hand, most frozen foods can be kept satisfactorily at 0° F. for at least a year. At lower temperatures, *e. g.*, -20° F., frozen meat, fruits, and many other products may be held for two years or even longer without noticeable deterioration in quality.

In order to produce frozen foods of good quality, care must be taken in the selection, preparation, packaging, freezing, and storage of the products, or else freezing and subsequent storage may ruin them. Until the advent of the so-called frosted foods, frozen foods were considered to be inferior to fresh foods. There are two very good reasons to account for this:

1. Little care had been given to the selection of the food to be frozen. Usually products for which there was no ready market were frozen. Often these foods were those which had stood around awaiting sale, and consequently had begun to deteriorate.

2. The products were frozen in bulk by ordinary slow or sharp freezing methods.

It should be obvious that the frozen food will not be any better than the product selected for freezing, and that, at best, freezing is merely an excellent way of preserving foods without noticeable deterioration of palatability and nutritive value.

Ordinary slow or sharp freezing methods commonly employed for freezing foods in bulk, as for example, for cold-pack fruits, large boxes of poultry, and fish, etc., require from 12 to 72 hours to complete the freezing operation. During this long period, most of the water content of the food separates in the form of large ice crystals. (See Figs. 48a and 48b, p. 325.) On thawing the food, the ice crystals melt and much drip or leakage occurs. In the case of haddock fillets, the leakage contains soluble proteins and other nutrient and flavorful components. When cooked, such slow frozen fish is likely to be dry and flavorless. Owing to the separation of such a large proportion of the moisture content of the foods, the proteins become more or less denatured because of dehydration and do not reabsorb all of the juice when the product is thawed. On the other hand, when fish and similar products are rapidly frozen, the ice crystals are so small that they cause little rupturing of cell walls. There is also relatively little denaturation of the proteins. When the product thaws, most of the liquid resulting from the small crystals is reabsorbed, the cooked product possessing an excellent flavor and texture. Quick freezing has yet another advantage, inasmuch as the products are quickly cooled below the temperature at which bacterial, mold, and yeast growth occur, thus preventing decomposition during freezing.

The freezing operation is only one of a number of steps, each of which is of importance in the preparation of a high-grade frozen food. The more important of these are selection of the raw material; preparation for freezing, (*e. g.*, washing, blanching, and cooling); packaging; freezing; and storing. Since each type of food is treated differently, a general consideration of these steps is difficult. Therefore, details of preparing and handling the several foods will be discussed under each type of product.

(a) Sharp Freezing

A large proportion of the commercial production of frozen foods are frozen in a sharp freezer. Strictly speaking a sharp freezer is merely a room which can be maintained at a low temperature, usually -10° F. or lower, throughout the freezing operation. It usually adjoins the room or rooms in which the products are to be stored.

In some sharp freezers, the refrigerant pipes or coils are arranged as shelves on which the products to be frozen are placed. In others, freezing is accelerated by forced air circulation. Cold diffusers or fans are employed for this purpose.

(b) Quick Freezing

There are many ways of accomplishing quick freezing. All fall into one or a combination of two of the following classes: direct immersion in a refrigerating medium, for example, brine freezing; indirect contact with a refrigerant, as by conduction through metal plates; and by convection in a blast of cold air.

Immersion freezing, formerly known as brine freezing, is one of the oldest systems of quick freezing. It was originally proposed for the freezing of whole fish in salt brine. The product was always slightly salty because of the penetration of the brine. More recently, the use of an invert sugar solution has been employed by Taylor and by Bartlett for the quick freezing of fruits, vegetables, and certain other foods. The Taylor freezer is sometimes known as the "TVA" freezer. That invented by Bartlett is called the polyphase freezer.

The *indirect contact system* of freezing usually involves engaging the product with a metal surface which is cooled by brine or some other refrigerant. The common method of making artificial ice by suspension of a can of water in a bath of brine is an example of freezing by indirect contact. In fact, the Petersen system of freezing fish involves immersing in brine deep, thin metal cans filled with fish. In this way, blocks of fish about 2 inches thick, 28 inches long, and 18 inches wide are obtained.

Kolbe has invented two types of freezing machines each effecting freezing by indirect contact. According to one system, known as the diving bell method, the fish to be frozen are placed in shallow metal pans fitted with telescoping metal covers. A number of these covered pans are placed in a frame and then lowered into a tank of refrigerated brine. The brine does not enter the pans because of the air seal which forms between the pans and the covers. The other system is known as the floating pan method and is sometimes used to freeze fillets of fish. By this method the fillets are placed in shallow circular pans which are then floated on refrigerated brine flowing through a series of shallow troughs. The system is so arranged that the flowing brine carries the pans completely around the series of troughs, returning them to the starting point. Thus the heat is extracted from only one side of the fillets. The Kolbe quick freezing methods have not been extensively used for foods other than fish.

The *Birdseye multiplate freezer* is more extensively used for freezing foods than any other freezer employing the indirect contact system. Its use is especially advantageous for the freezing of products in rectangular paperboard packages. This freezer (see

Fig. 49) consists of a number of superimposed refrigerated hollow metal plates which form shelves to receive packaged products to be frozen. The plates are actuated by hydraulic pressure in such a way that they may be opened to receive products between them and then closed on the product with any desired pressure. The series of plates is enclosed in an insulated cabinet. Each of the smaller machines, which are usually constructed with only six stations, has its own refrigerating unit located directly beneath the insulated freezing chamber. A number of the larger machines are hooked up with one large refrigerating system. The plates are usually made of rolled aluminum alloy. Ammonia or brine is circulated from a header through passages in the plates. The refrigerant passes out of the opposite end of the plates into a rubber hose connected to another header which carries the gas (in the ammonia type) to a surge drum located on top the machine.

Cooke, Hendron, Mathews, Murphy, Stone, and others have invented other mechanical systems of quick freezing food by indirect contact.

1. Fish

Most of the improvements in methods of freezing foods were originated for the purpose of better preserving fish. Quick freezing was first devised to improve the quality of frozen fish. As long ago as 1861, Enoch Piper froze fish rapidly by means of a mixture of salt and ice. He did not fully appreciate the advantages of rapid over slow freezing; and it remained for Plank and others to demonstrate the higher quality of rapidly frozen products.

(a) Sharp Freezing Methods

Large quantities of whole fish are sharp frozen (see Volume I, page 503) in galvanized iron pans. The rectangular pans, each filled with 25 to 35 pounds of fish, arranged in an orderly manner, are placed on refrigerant coils constructed so as to form shelves. Usually each pan has a few $\frac{3}{8}$ - or $\frac{1}{2}$ -inch holes in order to permit drainage. The pans are ordinarily somewhat larger at the top than at the bottom, thus allowing the easy removal of the frozen fish and the nesting of the empty pans.

After the fish have been on the shelves in the sharp freezer for about 24 hours, they are removed and glazed. Either glazing or packaging in moisture-vaporproof materials is necessary to protect the fish from desiccation and to reduce oxidation. The fish are removed from the pans by immersing them in cold water in the glazing tank. This warms the pans slightly, and thaws the ice bond between the metal and the fish, thus permitting the removal of the cakes of fish. The cake is allowed to remain a moment in the water, during which it becomes covered with a glaze of ice. The fish are given three or four dips. After each dip the cake of fish is allowed to remain out of the water long enough for the excess water to drain off. Four or six blocks of glazed fish are usually placed in a large wooden box for storage.

Large fish are handled individually and not frozen in pans. The fish are eviscerated

and then thoroughly washed. Sometimes they are also beheaded. They are then frozen on galvanized iron sheets laid on the shelves formed by the refrigeration coils.

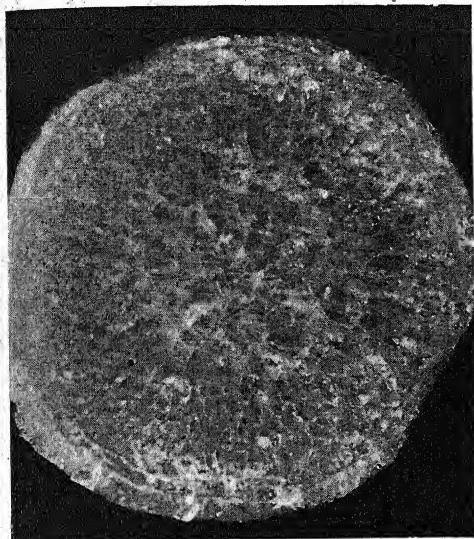


Fig. 48a.—Cross section of carrot frozen in still air at 0° F. (Courtesy Frosted Foods Sales Corp., New York City.)

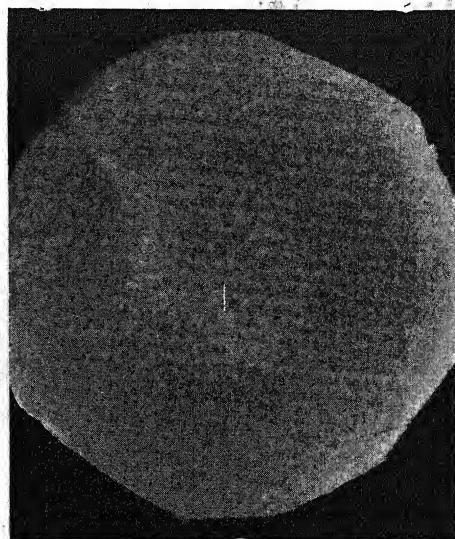


Fig. 48b.—Cross section of carrot quick frozen in Birdseye Multiplate Freezer. (Courtesy Frosted Foods Sales Corp., New York City.)

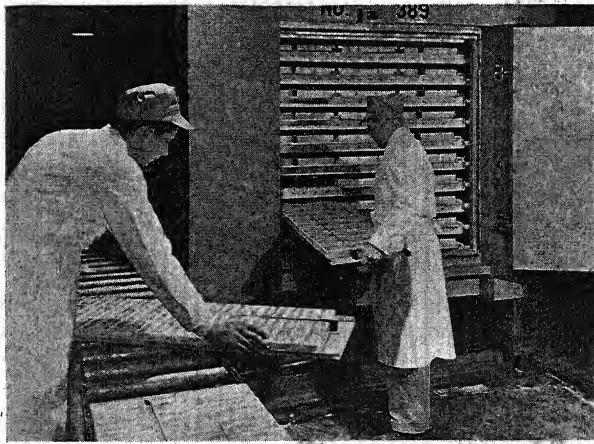


Fig. 49.—Loading Birdseye Multiplate Freezer with packaged asparagus. (Courtesy Frosted Foods Sales Corp., New York City.)

of the sharp freezer. When solidly frozen, e. g., after two or three days, the fish are removed, glazed, and placed in storage. Large fish are often put in wooden boxes, but

sometimes are merely arranged in regular piles. The latter procedures makes reglazing easy, since it is only necessary to sprinkle the fish with water from a hose.

(b) *Freezing of Fillets and Steaks*

Fillets of fish are obtained by cutting off the flesh of the fish from one side by running a knife down to and along the backbone. After one fillet has been cut from one side of the fish, it is turned over and the other fillet cut from the opposite side. Sometimes the skin is subsequently cut from the fillets. In other cases the fillets are frozen without skinning.

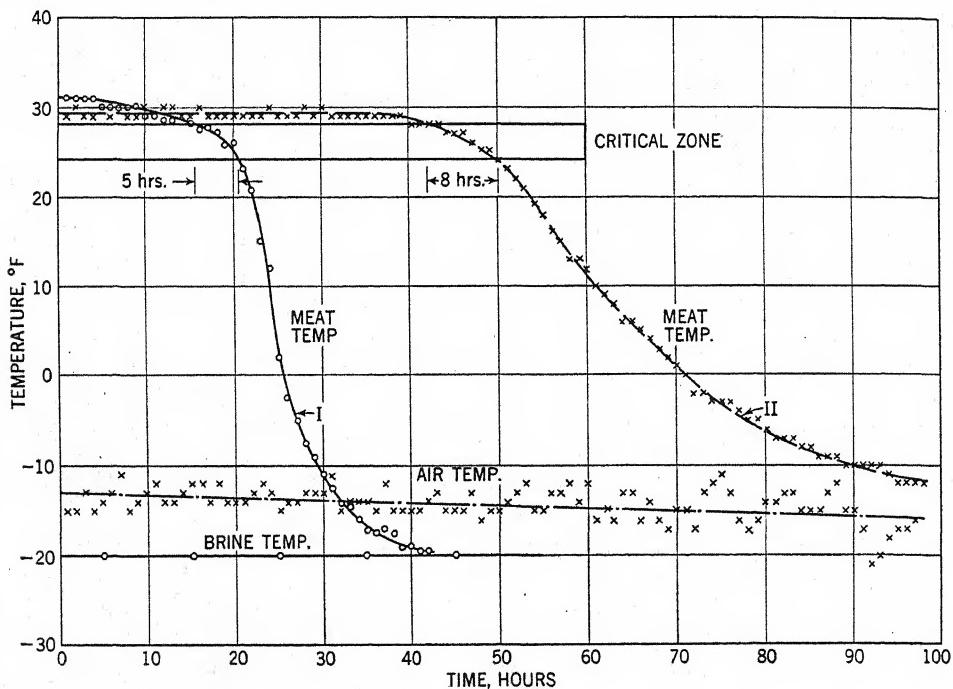


Fig. 50.—Still air freezing *vs.* brine spray freezing. All readings taken 5 inches in rump of hind quarter of beef. Curve I, brine spray; Curve II, still air. (Courtesy Dewey and Almy Chemical Co., Cambridge, Mass.)

Steaks are obtained by beheading the fish and then cutting one-inch sections one after another across the fish. Fillets are nearly free of bones, whereas each steak ordinarily contains one vertebra.

Fillets and steaks of lean fish such as haddock and cod are dipped for a short period (about 20 seconds) in a brine usually containing approximately 10% of common salt. This treatment reduces the tendency for the cut fish to drip after thawing. Fillets of fatty fish are not ordinarily dipped in brine.

Fillets and steaks are usually wrapped in moistureproof Cellophane or special vegetable parchment and then packaged in cold-waxed or tin containers. The common practice is to put either 5 or 10 pounds of fillets in a rectangular cold waxed carton with a telescoping cover. Birdseye multiplate freezers (see Fig. 49) are often employed for the freezing of packaged fillets and steaks.

2. Shellfish

Large quantities of shrimp are frozen in the United States. Limited amounts of scallops, squid, oysters, crabs, lobster and spiny lobster meat, and clams are also frozen. See Table 27.

TABLE 27
SHELLFISH FROZEN IN THE UNITED STATES IN 1941^a

	Pounds
Scallops.....	2,396,169
Shrimp.....	19,803,803
Spiny lobster tails.....	506,657
Squid.....	2,405,161
Other shellfish.....	1,575,899
Total	26,687,689

^a From "Fishery Products Frozen, and Cold Storage Holdings of Frozen and Cured Fishery Products in the United States and Alaska, 1941." U. S. Fish and Wildlife Service, *Current Fishery Statistics* No. 16 (1941).

Shrimp are frozen both before and after cooking; but the bulk of the pack is not cooked before freezing. The usual procedure is to remove the heads from the shrimp, then wash and pack them in rectangular 5- and 10-pound cartons which are then placed on coils in a sharp freezer. After freezing, the shrimp are usually glazed, often by brushing cold water on the top layer. After glazing, five or six 10-pound or ten or twelve 5-pound cartons are commonly packed in a fiberboard shipping container for storage or shipment.

When the shrimp are cooked before freezing, they are usually peeled first. The peeled shrimp are boiled about six minutes in 8 to 10% salt brine. After cooling, the cooked shrimp are packed in 5-pound tins or cartons for sharp freezing. Cooked shrimp toughen slightly during freezing and subsequent storage. Frozen shrimp should be stored at 0° F. or below.

Oysters are shucked, washed thoroughly with dilute brine, graded for size, and then packaged, usually in moistureproof, Cellophane-lined rectangular cartons. Birdseye multiplate freezers (see Fig. 52) are commonly used for quick freezing oysters. After removal from the freezer, the cartons are packed in corrugated fiberboard containers for shipping or storage at 0° F.

Clams and scallops are usually graded for size prior to shucking. Otherwise the procedure is the same as that described for *oysters*. Scallop "eyes" are packaged and frozen without special treatment.

Crabs and lobsters are ordinarily cooled before the meat is separated for freezing. Live crabs are steamed in retorts usually under pressure of 15 pounds. Soft crabs, however, are frozen without precooking. Lobsters are cooked by boiling in brine. The meat of the cooked hard crabs is picked from the shell and packaged in moisture-proof, Cellophane-lined, rectangular cold-waxed cartons, then either quick frozen in a Birdseye multiplate freezer or sharp frozen on refrigerated coils. Lobster meat is handled in a similar manner.

Spiny lobsters (*langouste*) are not cooked before freezing. The tail (which contains practically all of the edible meat) is broken from the body, and the alimentary canal removed. After washing, the tails are wrapped in moistureproof Cellophane, then packed in rectangular cold-waxed paperboard cartons and quick frozen in Birdseye multiplate freezers.

3. Poultry

Chickens are prepared and frozen in two distinctly different ways: New York dressed, then packed in wooden boxes and sharp frozen; or eviscerated, then quick frozen in Cellophane-lined or Cry-o-Vac packages. In addition some chicken for fricassee or frying is dressed and then cut up and packed in Cellophane-lined packages. See Volume I, page 533.

At present the great bulk of the frozen poultry is sharp frozen without evisceration. After slaughter, the birds are carefully bled, then semiscalded, rough picked, dipped in wax, and cooled with water. The hardened wax is stripped off, thus removing the remaining feathers, pinfeathers, and scales. After hanging overnight in a cooler, the heads are wrapped in paper and the birds are packed usually twelve to the box in a paper-lined wooden box. These boxes of poultry are stacked in a freezer, usually provided with forced air circulation, and maintained at -10° F. or below.

Chickens to be eviscerated are slaughtered and picked by the same methods employed in New York dressing. After removal of the pinfeathers by waxing, the birds are placed in pans. An incision is made in the abdomen which permits inspection of the viscera. After inspection, the head and feet are cut off and the bird is eviscerated. The eviscerated birds are carefully washed and the giblets wrapped in parchment paper and inserted in the abdominal cavity. Each chicken is wrapped in either moisture-proof Cellophane or packaged in a rubber latex bag. One or more wrapped birds are usually placed in a cold waxed carton and then quick frozen in a Birdseye or other suitable machine.

Ducks are prepared for freezing and frozen by both the procedures outlined for chickens. Some ducks are dressed New York style and then quick frozen in a fine spray of salt brine according to the process invented by Zarotschenzef commonly called the "Z" process.

Turkeys are also prepared for freezing and frozen by both the procedures outlined for chickens.

It should be noted that the skin of poultry desiccates unevenly, causing an unde-

sirable mottled appearance called "freezer burn." Further, poultry fat turns rancid comparatively rapidly because of oxidation during cold storage. Poultry should therefore be carefully packaged in moisture-vaporproof packages and stored at low temperatures, preferably -10° F. or below.

4. Meats

Large quantities of meat are frozen. Much of it is sharp frozen as halves or quarters of carcasses without special wrapping or other preparation. Much beef is now being boned, then packed in large packages and sharp frozen for use by the United States Army. This meat is of three types: beef for roasting and frying; beef for stewing and boiling; and ground meat. Each cut of beef for roasting and frying is wrapped separately in waxed kraft paper and then packed in fiberboard boxes containing 45 to 55 pounds. Stewing and boiling meat is wrapped in paper in units of not more than 10 pounds, then packed in the same size and type of fiberboard boxes used for roasting and frying beef. The ground meat is pressed into rectangular blocks and wrapped in paper.

Some meat is cut into pieces of the proper size and kind for use by the housewife, wrapped in moistureproof Cellophane, packaged either in a stockinet or in a carton, and then quick frozen in a Birdseye multiplate freezer or some other suitable machine. Roasts are usually inserted in stockinets, whereas steaks are usually put into cold-waxed cartons. Ground meat is put into small rectangular cartons lined with moisture-proof Cellophane. When solidly frozen, the packages of meat are placed in corrugated fiberboard containers for storage or shipment. Pork should be stored at below zero if the fat is to be kept in good condition for long periods. Zero to $+5^{\circ}$ F. is sufficiently cold for the storage of beef and lamb.

5. Dairy Products

Ice cream is, of course, the most important dairy product frozen in the United States, approximately 375,000,000 gallons being manufactured annually. More than half (about 55%) of this is flavored with vanilla. Frozen desserts may be classified as follows: plain or standard ice cream; custard and French vanilla (ice cream containing eggs); iced milk (a frozen dessert with fat content standard set lower than the standard for ice cream); ices (fruit juices, sugar, and flavor); and sherbets (like ices, except that they contain milk).

The standard mix is usually about as follows: 12 to 14% butter fat, 15% sugar, 10% milk solids not fat, and from 0.2 to 0.5% gelatin or other stabilizer. In making ice cream, the usual procedure is pasteurizing the mix at 150° F. or higher for 30 minutes. Then it is homogenized using a pressure of 2000 to 3000 lbs. per sq. in. on the first stage and 800 to 1500 lbs. per sq. in. on the second. Single-stage homogenizers operate on only one pressure (2000 to 3000 lbs. per sq. in.). The mix is then cooled to about 40° F. and held at this temperature for a few hours before freezing. Small lots of ice cream are frozen in batch freezers. Larger quantities are frozen in continuous

freezers. By either method of freezing the mixture is rapidly agitated for the following reasons: to whip in enough air to give the desired increase in volume (overrun); to obtain rapid heat transfer and thus rapid freezing; and to produce small crystals. In any case, the ice cream is withdrawn from the freezer when it begins to stiffen. It is put into the containers, usually metal or paperboard tubs, in which it is to be sold, and moved into a room maintained at about -20° F. for hardening.

Considerable quantities of heavy cream are frozen in large containers for later use in the commercial manufacture of ice cream, etc. Although it is generally recognized that a superior *frozen cream* may be obtained by rapid freezing, still the product is almost entirely slow frozen or sharp frozen in slip cover cans holding approximately 50 pounds each. Even when low freezing temperatures are employed, the butterfat tends to separate during thawing, and, further, in storage it sometimes takes on a tallowy flavor. However, since either the cream itself or the product (*e. g.*, ice cream mix) in which it is used is homogenized, and, since at the time it is used it is often mixed with some fresh milk and cream, these qualities are not considered highly objectionable.

Frozen milk is also sometimes prepared; but unless the milk is pasteurized, concentrated, and homogenized prior to freezing, the emulsion is so badly broken down and possesses such a tallowy flavor that the product is undesirable.

The method followed in preparing milk for freezing is the same as that used in preparing evaporated milk for canning. It is usually frozen in 50-pound slip cover tin cans in a sharp freezer.

Much *butter* is held in storage at temperatures of 0° F. or even as low as -20° F. Ordinarily, special containers are not provided. In other words, it is held in the customary packages or tubs.

6. Eggs

When egg white is frozen and then thawed it returns to its original consistency and appearance. When pure egg yolks are frozen and chilled below about 22° F., the yolk changes to a jelly which does not become fluid even when the temperature is raised to 70° F. Mixed whites and yolks become more viscous on freezing and thawing but do not actually jell. Commercially, egg yolks are mixed with sugar, corn syrup, salt, or glycerol prior to freezing. The addition of about 5% of any one of these ingredients prevents the jelling of the egg yolk during freezing.

Whole eggs (mixed whites and yolks), whites, and yolks are usually frozen in 30- or 50-pound slip cover tin cans which are placed in a room maintained at -10° F. or lower. In some instances, forced air circulation is provided. Storage should be at 0° F. or lower.

7. Fruits

Large quantities of fruits are frozen annually in the United States. Strawberries, cherries, raspberries and other small berries, peaches, and apples make up the bulk of

the pack. Much of the fruit is slow or sharp frozen in large containers for the use of jelly, jam, and preserve makers, bakers, ice cream makers, and other large commercial users. This product is known as cold pack or frozen pack fruit. A smaller quantity of fruit, consisting principally of strawberries, raspberries, and peaches, is quick frozen in small containers for use by the consumer for dessert purposes.

Freezing, cold storage, and subsequent thawing of unprotected fruit bring about certain undesirable changes in the texture of the fruit and also permit the oxidation of the pigments and many of the flavoring components. In order to hold these undesirable changes to a minimum, fruits are usually either mixed with sugar or covered with sugar sirup.

(a) *Cold Packed Fruit*

In the Pacific Northwest, *strawberries* are picked without caps. Therefore they require only washing and grading according to size in order to prepare them for cold packing. They are mixed with sugar as they are run into 30- or 50-pound slip cover tin cans or 50-gallon barrels, usually in the proportion of two parts of strawberries to one of sugar (a "2 + 1" pack) or of three parts of berries to one of sugar. *Raspberries*, *boysenberries*, *youngberries*, and *loganberries* are similarly handled, although these smaller fruits are usually packed in slip cover tin cans either without sugar or with only a small amount. Barrels of fruit packed with sugar are rolled into a room maintained at about -10° F. which is usually provided with forced air circulation. After 48 hours in this sharp freezer, the barrels are moved into a storage held at +10 to +15° F. During freezing and the first few days of storage, the barrels are rolled daily in order to obtain a better mixture of sugar and fruit.

Montmorency cherries, picked without stems, are chilled in iced water for a few hours in order to firm them. The chilled fruit is pitted in mechanical pitters, and then mixed with sugar either in 30- or 50-pound tin cans or in 50-gallon barrels. The cans or barrels are moved into a freezer maintained at 0° F. or below. Cherries are usually stored at 0 to +5° F.

(b) *Quick Frozen Fruit*

Sliced strawberries are the most popular fruit sold for the consumers' use as a dessert. The berries are either picked without caps (as in the Pacific Northwest and some other sections) or are picked with caps and then capped at the freezing plant. The capped berries are washed, sorted to remove underripe, mushy, and insect-bitten berries, and then passed through a slicer which cuts them into $\frac{1}{4}$ - or $\frac{3}{8}$ -inch slices. The sliced berries are mixed with sugar usually in the proportion of either 4:1 or 5:1. The product is usually filled into bags standing in rectangular cold-waxed cartons (about 4 × 5 × 1 $\frac{1}{2}$ inches in dimensions). The bags are heat sealed, and the cartons closed and overwrapped with a heat sealing transparent paper. The filled packages are placed in Birdseye multiplate freezer or some other quick freezing machine. When

solidly frozen, the packages are put into corrugated fiberboard shipping containers for storage at 0° F.

Peaches are also sliced, put into bags in small packages, and then covered with a heavy sirup, usually about 60%. The use of the sirup prevents direct action of the oxygen of the air, and thus inhibits browning.

Raspberries, *youngberries*, *boysenberries*, and *loganberries* are not sliced but may be crushed with sugar, or covered with heavy sirup, or merely packed dry. In most instances, those crushed with sugar have the best flavor.

Some *cherries* are packed in small containers for sale at retail. Ordinarily the pitted fruit is merely mixed with sugar, in the proportion of about 3:1, prior to packaging.

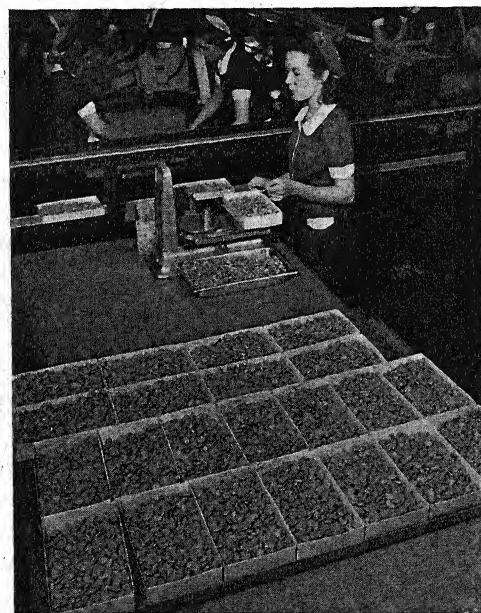


Fig. 51.—Packaging precooled Fordhook Lima beans in 12-oz. and 2½-lb. cartons. When filled, the weight is checked and the cartons are placed on screen trays for delivery into quick freezers. (Courtesy California Consumers Corp., Los Angeles, Calif.)

8. Fruit Juices

Most fruit juices can be preserved by freezing without the occurrence of noteworthy changes. Apple, cherry, raspberry, loganberry, pineapple, and many other juices are not changed noticeably by freezing and cold storage for many months. Freezing and thawing cause the precipitation of the suspended matter of certain pulpy juices, for example, of tomato and orange juices. However, shaking or homogenizing the juice after thawing brings about the dispersal of the precipitated solids. Orange juice must be freed from dissolved oxygen prior to freezing if its flavor is to be retained. Special

care must be taken to reduce the tartrate content of grape juice prior to freezing, or considerable amounts of tartrate crystals will be deposited.

Apple, cherry, raspberry, and loganberry juices can be frozen satisfactorily in large containers provided the juice has been cooled to 45° F. or lower prior to filling into the cans or barrels in which it is to be frozen. Of course, the containers cannot be filled more than nine-tenths full; otherwise the expansion which occurs during freezing will burst the containers. If tin cans are employed as containers, they should have an enamel lining suited to withstand the corrosive action of the acids of fruit juices.

Orange, pineapple, and tomato juices should be deaerated completely, then packaged in suitable containers and quick frozen. Flash heating to 190° F. after deaeration is advantageous but not absolutely essential. Flash heating inactivates enzymes which may cause clarification and changes in flavor. Considerable quantities of orange juice are quick frozen in cans in Finnegan tubular freezers. According to this procedure, sealed cans of orange juice are passed through tubes filled with rapidly flowing refrigerated alcohol.

9. Vegetables

Many vegetables may be preserved better by freezing and cold storage than by any other method. Broccoli, Lima beans, yellow sweet corn, peas, spinach, Brussels sprouts, cauliflower, asparagus, green shelled beans, beets, carrots, edible soy beans, and a few varieties of green snap beans yield especially desirable products. All varieties of a given vegetable do not freeze equally well. In most instances, the varieties grown in home and market gardens give products superior to those produced for canning.

If untreated vegetables are frozen and held in cold storage for more than a few days, their flavor and aroma will change because of the action of enzymes. For this reason it is necessary to inactivate the enzymes of vegetables by blanching (precooking) them prior to freezing. See page 312. This is usually a very simple process, involving merely the heating of the prepared vegetable either in steam or in water near the boiling point for a period long enough to bring the center of each vegetable or piece of vegetable up to a temperature of 200° F. or above. The length of time required for blanching depends principally upon the medium used, the temperature of the medium, the temperature of the product, the rate of circulation of the medium, and the size of the vegetable or the pieces of vegetable. Shelled peas, being small, need only about 60 seconds in boiling water or live steam, whereas large ears of sweet corn require 8 to 10 minutes in the same media.

In general, the process of preparing and freezing vegetables may be summarized as follows: Vegetables of the proper variety and maturity are selected and harvested. The freshly harvested vegetable is carefully washed, cleaned, inspected, and prepared as for cooking. It is then blanched for a period long enough to inactivate the catalase content and immediately cooled to 60° F. or lower in cold water. The product is given a final inspection, then packed in moisture-vaporproof cartons (see Fig. 51).

X. PRESERVATION BY TEMPERATURE CONTROL

TABLE 28
STEPS IN THE PREPARATION OF VEGETABLES FOR FREEZING^a

Vegetable	Maturity desired	How prepared		Best scalding medium	Optimum scalding period
Asparagus	Tender tips best	Cut spears to 6-inch length	Steam	Boiling water	3½ min.
Beans, green	Before pods dry	Shell	Boiling water	10 sec.	4½ min.
Beans, Lima	Green beans best	Shell	Boiling water	Small beans.....	1 min.
Beans, snap	Small beans best		Boiling water	Medium beans.....	1½ min.
Beets	Young and tender		Boiling water	Large beans.....	2 min.
Beet greens	Young and tender		Boiling water	1½-in. diam.....	2½ min.
Broccoli	Compact heads		Boiling water	Over 2-in. diam.....	cook until tender
Brussels sprouts	Dark green compact heads	Cut sprouts from main stem	Boiling water	Small pieces.....	3 min.
Carrots, sliced	Young and small	Top, scrape, then cut into ¼-inch slices	Boiling water	Medium pieces.....	4 min.
Cauliflower	Solid heads	Cut heads into pieces not thicker than 1 inch	Boiling water	1/4-in. slices.....	70 sec.
Chinese cabbage	Solid heads	Cut individual leaves from stem	Boiling water	1/4-in. slices.....	4 min. ^b
Eggplant	Mature	Peel, slice in ¼-inch slices	Boiling water	Large size.....	10 sec.
Kale	Young and tender	Cut off tops and discard main stem	Boiling water	Small size.....	10 sec.
Kohlrabi, diced	Young and tender	Cut off tops, peel, dice in ¼-inch cubes	Steam	Large size.....	70 sec.
Mushrooms	Small size with white, tight caps	Cut off base of stems	Boiling water	Small size.....	3 min. ^b
Mustard, curly	Young and tender	Cut off and discard main stem	Boiling water	Large size.....	4 to 5½ min. ^b
New Zealand spinach	Young	Cut off and discard main stem	Steam	50 sec.	50 sec.
Peas	Sweet and not starchy	Shell, discard starchy peas	Boiling water	Small peas.....	70 sec.
Rhubarb	Early spring rhubarb best	Eliminate leaves; cut stems into 1-inch lengths	Boiling water	Large peas.....	45 sec.
Spinach	Young	Cut and discard thick stems	Boiling water	90 sec.	1 min.
Squash, summer	While tender, before rind hardens	Slice in ¼-inch slices	Boiling water	3½ min.	3½ min.
Squash, winter	Fully mature, with hard rind	Peel, cut in 1-inch cubes; cook until soft, mash	Boiling water	Small ears.....	6½ min.
Sweet corn, on cob	Before starchiness develops	Husk, eliminate under- and overmature ears	Steam	Medium ears.....	8½ min.
Sweet corn, cut	Before starchiness develops	Either scald on cob as directed above, cool, then cut off whole kernels; or cut whole kernels from cob, then scald	Boiling water	Large ears.....	10½ min.
Swiss chard	Small leaves best	Cut off and discard main stem	Steam	2½ min.	2½ min.
Turnips, diced	Young and tender	Cut off tops; peel, dice in ¼-inch cubes	Boiling water	Cool first in 2% citric acid solution, then cold water.	70 sec.
Turnip, greens	Young and tender	Eliminate all coarse large leaves	Steam	60 sec.	60 sec.

^a D. K. Tressler and C. W. Dubois, N. Y. State Agr. Expt. Sta., Bull. 690 (1940).

^b Cool first in 2% citric acid solution, then cold water.

and quick frozen. After freezing, the packages are placed in corrugated fiberboard shipping containers and stored at 0° F. or lower.

Considerable quantities of peas, snap beans, and some other vegetables are frozen on meshed wire belts or on trays without packaging. The resultant product is free flowing (*i. e.*, can be poured). The frozen product can be packed in either large or small containers.

A tabular summary of procedures recommended for the vegetables commonly frozen is presented as Table 28.

Storage of frozen vegetables should be at 0° F. or below.

IV. MARKETING OF FROZEN FOODS

The marketing of frozen foods offers many problems. As a general rule, frozen foods remain in the best condition only if they are maintained at a uniformly low temperature (preferably 0° F. or below) right up to the time of use. Thawing and refreezing severely damages nearly all foods. Specially insulated cars and trucks refrigerated by mechanical means or with either crushed ice and salt or with dry ice should be used for the transportation of these products. When frozen foods are sold at retail, mechanically refrigerated cabinets, maintained at a temperature not higher than +5° F., should be employed for storage and display purposes.

Chapter XI

THE PRESERVATION OF FOOD IN HERMETICALLY SEALED CONTAINERS

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For all practical purposes, it may be considered that fresh succulent foods normally carry microorganisms which will cause spoilage if not restrained in their activity. The basis upon which the preservation of food in hermetically sealed containers rests is the destruction of these microorganisms by heat and the prevention of the entrance of others. No chemical preservatives are required or used; and no especial conditions of storage or handling after heat treatment are necessary. The preservation of foods in hermetically sealed containers through the agency of sterilization by heat is called canning.

There are a number of food products which are frequently packaged in hermetically sealed containers for one or another reason, but for which this type of package has little significance in connection with preservation. It may be used as a protection against insect infestation, against dust, to prevent the entrance or loss of moisture, to delay quality deterioration, or for some other reason which, in the opinion of the manufacturer, justifies this style of container. The fundamental basis upon which the preservation rests, however, is to be found elsewhere than in hermetic sealing. Such products, therefore, are outside the scope of this chapter.

The earliest record of the preservation of putrescible materials by heating in hermetically sealed containers is to be found in the classic work of Spallanzani. In 1765, in connection with his experiments on the origin of life, he found that organic infusions could be protected against spoilage by prolonged heating in a well-corked bottle. The one who justly receives credit as the father of the canning industry, though, is the French confectioner and baker, Nicolas Appert. He was the first consciously to employ heat and hermetic sealing in the preservation of food. During the Napoleonic Wars, the need for a method of preserving food for army use was so great that the French Government offered a prize of 12,000 francs to anyone who could devise a method of food preservation which would insure wholesome food. Appert attacked the problem and, in 1804, after several years of experimentation, samples which he submitted were found to be acceptable. In 1810, the prize was awarded him and aided him in establishing the House of Appert, a commercial canning organization which has maintained a continuous existence.

In 1807, in England, Thomas Sadington, probably influenced by the work of Appert, reported a method of preserving fruit by heating in a water bath in loosely corked bottles, which were tightly corked and sealed with cement after removal from the bath.

Augustus de Heine and Peter Durand obtained British patents, in 1810, covering the use of iron and tin-plate containers, respectively, for preserving food; but neither engaged in canning on a commercial scale. However, shortly after the publication of Appert's method in 1810, there was developed in England by Hall and Donkin a procedure for the preservation of food in tinned containers. There is ample evidence that their products met with a favorable reception and were supplied to several expeditions and to the Navy.

The first canning in the United States was done by Thomas Kensett and Ezra Daggett, who, in 1819, began packing sea foods in New York City, using glass containers and heating in boiling water. About 1820, William Underwood canned fruits, pickles, and condiments in glass jars at Boston, founding a firm which is still active and is, therefore, only slightly younger than the House of Appert. The first attempt to can the sweet corn for which Maine is justly famous was made by Isaac Winslow, in 1839; by 1852 he was sufficiently successful to justify an application for a patent, which was granted in 1862.

Between 1840 and 1850, canneries for sea food were established in New Brunswick and in Baltimore, and tomatoes were canned in Pennsylvania by Crosby. The next decade saw commercial canneries started in New York, Maryland, and Delaware. Great impetus to the canning industry was given by the War between the States with its demand for preserved food. Canned food production increased sixfold between 1861 and 1865, and there has been a steady growth since that time, both in the number of factories and in the variety of products packed. In 1942, there were about 3300 factories distributed among 46 of the States of the Union, Hawaii, Alaska, and Puerto Rico.

The growing importance of the industry led, in 1907, to the organization of the National Canners Association; and, in 1913, the Research Laboratory of the Association was established in Washington. Branch laboratories were established in Seattle, in 1919, and San Francisco, in 1926. The work of these laboratories, and of the research departments of the various can manufacturers and large packers, has made possible the present high quality of canned food at low cost.

Approximately 375 different foods and food combinations are preserved by canning. This figure applies to peacetime production; under wartime restrictions prevailing in 1943, this number has been drastically reduced as a means of steel and tin conservation. And during peacetime, the number is constantly increasing, so that only temporary significance can be attached to the figure given. The list includes practically all of the fruits and vegetables grown, a wide variety of meats and meat specialties, sea foods (see Volume I, pages 504-509), soups, strained and chopped foods for infant feeding, fruit and vegetable juices, and many specialties such as ready-made entrees, breads, puddings, sauces, etc. The annual pack of all products runs into many billions of cans.

annually, and has a monetary value such that the canned food industry ranks as one of the major industries of the nation.

The volume for each of several recent years of a few familiar vegetables and fruits is given in Table 29, based upon data assembled by the National Canners Association,¹ and presented upon the basis of cases of 24 No. 2 cans, unless otherwise indicated.

TABLE 29
ANNUAL PACK OF SOME COMMON VEGETABLES AND FRUITS^a

Pack	1937	1938	1939	1940	1941
1. VEGETABLES					
Asparagus ^b	2,703,966	2,403,214	2,519,892	3,108,562	3,104,296
Green and wax beans	10,051,843	10,914,997	8,486,670	9,798,144	13,362,284
Beets	3,210,403	3,176,207	2,270,982	3,719,353	7,365,326
Corn	23,541,224	20,469,518	14,566,914	15,523,579	26,109,140
Peas	23,467,479	25,458,647	16,074,109	25,195,640	28,723,546
Spinach	6,121,653	2,892,350	4,055,381	4,980,236	4,946,253
Tomatoes	26,234,829	23,130,892	24,465,480	29,533,005	31,759,140
Tomato juice	16,979,057	11,234,567	13,658,619	15,086,168	23,390,935
2. FRUITS					
Apricots ^b	5,727,996	1,729,486	3,541,270	2,264,210	4,351,840
Red pitted cherries ^b	2,471,982	1,694,813	3,154,721	3,422,873	2,064,475
Grapefruit ^b	4,279,240	3,654,697	4,228,620	4,072,552	3,152,643
Grapefruit juice ^b	6,016,240	8,021,828	9,199,246	9,657,186	14,070,736
Peaches ^b	13,879,554	10,400,358	12,116,173	11,463,883	14,778,415
Pears ^b	5,115,962	4,848,090	4,803,403	5,787,800	6,848,497

^a Expressed as cases of 24 No. 2 cans.

^b Actual cases, all size cans.

I. PRELIMINARY CONSIDERATIONS

1. The Container

The characteristics of an ideal container for canned food have been given as follows:²

1. Strong enough to protect its contents adequately in shipment.
2. Readily fabricated into desired sizes.
3. Light for economical handling.
4. Readily opened.
5. Impervious to air and water.
6. Of pleasing and sanitary appearance.
7. Not harmful or toxic to the contents.

¹ *Canned Food Pack Statistics: 1941. Part 1: Vegetables; Part 2: Fruits.* Natl. Canners Assoc., Washington, D. C., 1942.

² "Tin Plate and Tin Cans in the United States," *Bull. 4. International Tin Research and Development Council*, New York, 1936.

8. Capable of being heated for sterilization.
9. Inexpensive, preferably cheap enough to discard after use.

In addition, the ideal container should be capable of being readily hermetically sealed. These qualities are very well met by either tin-plate or glass containers.

(a) *The Tin Can*

Although the earliest canning was done in glass, within a few years containers fabricated from tin plate came into use. These were first called "tin cannisters;" but the term was shortened to "can" by the Underwood bookkeeper, and this is the name used in the United States. In England, the container is called a "tin" and the food is referred to as "tinned food."

For many years, cans were made by hand and were either of the open-top, hand-soldered style or the "hole and cap" type. About 1900, the "sanitary" can, which is sealed mechanically without the use of solder, was developed, and has since come into practically universal use. (See Fig. 52, page 341.) These are made mechanically on a series of machines known as a can line at a rate in excess of 300 per min., as contrasted with the earlier daily output by an expert tinsmith of about 60 cans.

The material from which the can is made consists of a steel base plate coated with tin to give the familiar tin plate. Prior to the acute need of tin conservation occasioned by the war with Japan, the tin coating was applied by dipping the base plate in a bath of molten tin. This "hot-dip" plate normally consisted of about 98.5% iron and 1.5% tin. The generally accepted minimum weight of coating which can be satisfactorily applied by the hot-dip method is 1.25 lbs. per base box. (A base box is that quantity of tin plate which has on one side a total surface area of 31,360 sq. in. regardless of dimensions. The weight varies with the weight of the base plate, but with plate for food cans is near 100 lbs.) A wide range of coating weights can be applied by the electrolytic deposition of tin, and tin-plate manufacturers generally have installed equipment for making electrolytic plate. Details of the various methods of deposition have been given by Lippert.³ In 1942, plate with a coating of 0.5 lb. per base box was specified for cans for all or a major part of the pack of the noncorrosive products, and with some of these products untinned plate, which has been chemically treated to reduce rust formation, was likewise specified for use as can ends.⁴ The corrosion resistance of the lighter tin coatings is not so great as the heavier, and for some products a coating weight of 1.5 lbs. for both can body and ends is the minimum which will give a satisfactory container life.

Electrolytic plate has become of importance because of a scarcity of tin; but it is possible that it may be developed to such an extent as entirely to replace hot-dipped plate for some products.

In the manufacture of cans from any type of plate, the can may sometimes be enameled. Two major types of enamels or lacquers are used: "Sanitary," also known

³ T. W. Lippert, *Iron Age*, 149, 29 (1942).

⁴ Conservation Order M-81, as amended December 9, 1942.

as R or fruit enamel, for acid products, and "C" enamel. The latter is used for sulfur-bearing foods of the low-acid type to prevent discoloration of the food and unsightly staining of the can. Sanitary enamel is used primarily to prevent color loss in pigmented fruits or colored vegetables such as carrots and beets.

Within the industry there has developed a system of nomenclature which avoids the confusion arising from the conflicting local names for different can sizes. In this system, the approximate dimensions of the can are identified by numbers of three digits. The first whole number given indicates the diameter of the can and the second, the height. The first digit gives the number of whole inches and the next two digits, the additional fraction of an inch in sixteenths. Thus the common No. 2 can is referred to as a 307×409 , which means that the diameter and height are approximately $3\frac{7}{16}$ in. and $4\frac{9}{16}$ in., respectively.

Cans may be obtained in a wide variety of sizes and in several different shapes, depending upon the commercial practice for the particular product to be canned and the desire of the packer.⁵ Within recent years there has been a tendency to reduce the number of sizes used for fruits and vegetables in accordance with recommendations made by the Division of Simplified Practice of the National Bureau of Standards.

(b) Glass

Although the major portion of the food canned is packed in cans, there is a considerable quantity packed in glass. Glass is not a substitute for cans but an alternate container which has as its chief advantages the visibility of the contents and the insolubility of the container. It has the disadvantage of requiring greater care in handling; but this is compensated for, to some extent, by the development in recent years of glass with a high resistance to mechanical and thermal shock. Additional disadvantages are the greater shipping weight of glass, and the requirement of a larger amount of man power, as compared with cans, for a stated volume of production.

Glass containers may be had in a great variety of shapes and colors, and a number of different closures are available, not all of which are suitable for heat processing. Most of the heat-processed, glass-packed foods are sealed with a metal cap which carries a rubber gasket to insure hermetic sealing.

(c) Plastics

Much attention within recent years has been devoted to nonmetal, nonglass materials as substitute or alternate containers for food. So far no plastic or fiber has been developed which is fully satisfactory for heat processed foods.

2. Equipment and Materials Used for Equipment

In the early days of canning, most of the operations were performed by hand. Much hand labor is still required, but with the passage of time there has been a considerable

⁵ Conservation Order M-81 and its various amendments specify the sizes permitted for each product which may be packed under wartime restrictions.

development of food handling machinery. Thus beets, carrots, and similar root vegetables are peeled mechanically, cherries are pitted, apples are peeled and cored, corn is husked, cut from the cob, and the silk removed, peas are shelled, beans are snipped and cut, cabbage for kraut is cored and shredded, fruits and vegetables are sliced or diced—all of these and many other operations are done rapidly and efficiently by ingenious machines, which frequently are limited to a single operation on a single product. Much of this machinery is manufactured commercially according to a standard design, but in any factory there is likely to be some equipment which has been designed and built locally. See pages 17 *et seq.*

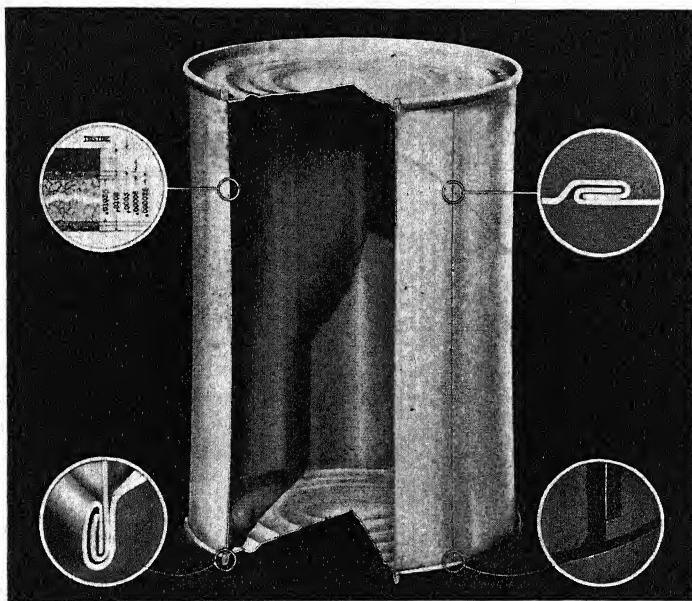


Fig. 52.—Details of structure of the "sanitary" tin can. Upper left: enameled tin plate in cross section, highly magnified, showing approximate thickness in fractions of inch, of various layers—steel base, tin-iron alloy, tin coating, and enamel. Upper right: side seam in cross section. Lower left: double seam in cross section. Lower right: notch (end of seam) showing construction which avoids excessive thickness of double seam. (Courtesy *Fortune Magazine*, January, 1941, Emil Lowenstein, American Can Co.)

In order to facilitate cleaning, food handling machinery is so constructed that the parts which come in contact with the food are readily accessible and, in most instances, easily dismantled. The maintenance of clean and sanitary conditions is made easy by the use, wherever practicable, of materials which are impervious to liquids. See pages 229 *et seq.*

It is of especial importance from the standpoints both of durability and of metallic contamination that the material used should be noncorrosive for the particular prod-

uct being canned. Where beets, for example, come in contact with exposed iron during the later stages of canning there may be an injury to the appearance of the finished product because of the uptake of sufficient iron to give a surface darkening. Corn may be so dark as to be unmerchantable due to the presence of minute traces only of copper. Copper contamination also must be avoided with those products in which ascorbic acid is of nutritional significance because of the catalytic action of copper on the oxidation of this vitamin. The choice of what material to use in fabrication of food handling machinery is, therefore, governed to a marked degree by the nature of the product to be canned.

3. Selection of Variety of Product to Be Canned

So far as the appearance of the finished product is concerned, not all varieties of fruits and vegetables, nor all cuts of meat, are equally satisfactory for canning. Like-

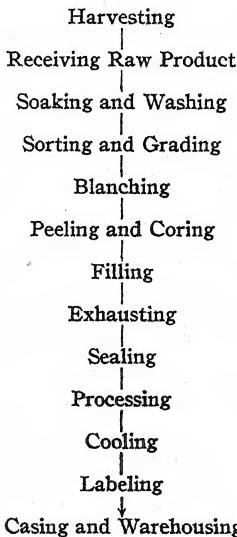


Fig. 53.—Typical commercial canning operations.

wise, not all varieties of the same fruit or vegetable are of identical flavor or color. Some may yield a canned product fully satisfactory as to flavor, but less satisfactory as to appearance, than others. Thus certain varieties of some fruits may give a ragged segment and a cloudy sirup, while others will have a smooth segment with a firm texture in a clear sirup. Certain types of white potatoes will become soft and break up as a result of processing, while other types retain a firm texture. If all desirable characteristics of flavor, appearance, and texture of the finished product can be supplied by a particular variety, no problem in selection exists. When they cannot be, then a selection, which is largely dictated by consumer acceptance, must be made on

the basis of the characteristic which the packer wishes to emphasize. Under any circumstances, the only safe criterion in the selection of a variety for canning is a trial pack made under the commercial conditions of packing.

4. Water Supply

A fundamental requirement for the preservation of food in hermetically sealed containers is an abundant supply of water of good chemical and bacteriological quality. See page 828. Water is necessary for the generation of steam, for soaking and washing the product, in the preparation of brine and sirup, for cooling the finished product, and in the maintenance of cleanliness of the factory and equipment. The quantity required will vary with the product being handled, but probably will be approximately 3 gal. per No. 2 can packed.

The water used for steam should not have objectionable amounts of scale forming or corrosive chemicals. That which is used for cooling likewise should be low in corrosive chemicals, especially chlorides and sulfates, or else an external corrosion of the cans is likely to occur. The use of hard water in soaking, in blanching, and in the brine is objectionable with peas and ripe beans because of an increased toughness of the canned product. Calcium is not, however, objectionable with all products, and may be added to tomatoes in order to make the canned product more firm. There is evidence that added calcium also improves the firmness of canned shrimp.

Water which is used in the various washing operations and in the preparation of sirup and brine should be of good sanitary quality. Water for the general cleanup need not necessarily be fit for drinking purposes; but it is preferable that it be so, since the use of a dual water system is undesirable.

II. BASIC OPERATIONS IN CANNING

1. Preliminary Preparation of Raw Product

The procedure followed in preparing a raw product for canning is dictated by the nature of the product. Peas, for example, must be removed from the pod, washed, graded for size, and picked free of extraneous material, splits, broken peas, etc. Corn must be husked, washed, and trimmed free of imperfections before cutting from the cob. Tomatoes must be soaked and washed to remove soil, scalded, and peeled and cored. Fruits must be washed and, depending upon the fruit and the style of pack, may or may not be peeled and pitted. Fish must be scaled, cleaned, and trimmed. About the only general statement which can be made is that the raw product is freed of all foreign or undesirable material which may be attached, and is carefully inspected and trimmed free of imperfections and faults. Later operations vary with the material handled.

2. Blanching

Many, but not all, fresh foods are given a hot water or steam wash, known as the blanch, before filling into the container. This serves to remove surface materials

which might injure the flavor, drives out gas, and wilts the product so that a better control of the fill is possible. In some instances it has a beneficial effect on color; and it is sometimes of value because of the destruction of enzymes.

3. Filling

Filling may be accomplished mechanically or by hand. Mechanical filling is faster, and gives a more accurate control of the net weight or volume of liquid. It is, consequently, used wherever possible. Such products as sardines, asparagus, and a number of others cannot be handled satisfactorily by mechanical fillers and must be filled by hand.

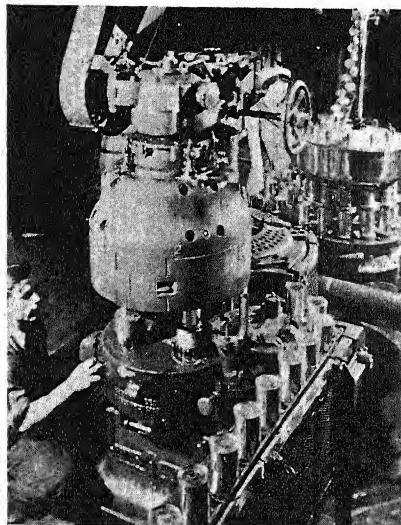


Fig. 54.—Filling and sealing tomato juice. Filler in background, sealing machine in foreground. Cans are sealed on this type of machine at the rate of about 130 per minute. (Courtesy National Canners Association.)

4. Brining or Siruping

At the time of filling or immediately after, it is customary to add a weak brine to most vegetables, and sirup to fruits. Water may be used instead of brine or sirup in some styles of pack.

5. Exhausting

The objective of the exhaust is to remove air and gas from the can so that the contents will be in a vacuum after processing and cooling. See page 58. The reasons for a vacuum may be summarized as follows:

1. It is one indication of sound packing procedure.
2. It reduces the strain on the container during processing, thereby preventing the buckling of the ends.

3. With some products, it is necessary to prevent discoloration and undesirable oxidative effects.
4. With certain corrosive products, it acts to lengthen the life of the container.
5. It prevents bulging of the can ends under conditions of high altitude or tropical temperature.

The vacuum may be secured by the use of heat or by mechanical means. Some products, notably cream-style corn, are preheated before filling and are sealed hot. With products which cannot be filled hot it may be necessary to pass the cans through a steam chamber or tunnel just ahead of the sealing machine, although sometimes the addition of hot water, brine, or sirup is adequate to insure a vacuum. In some cases, the air in the head space of the container is replaced with steam. Whatever the method used, a vacuum will result when the container cools after processing.

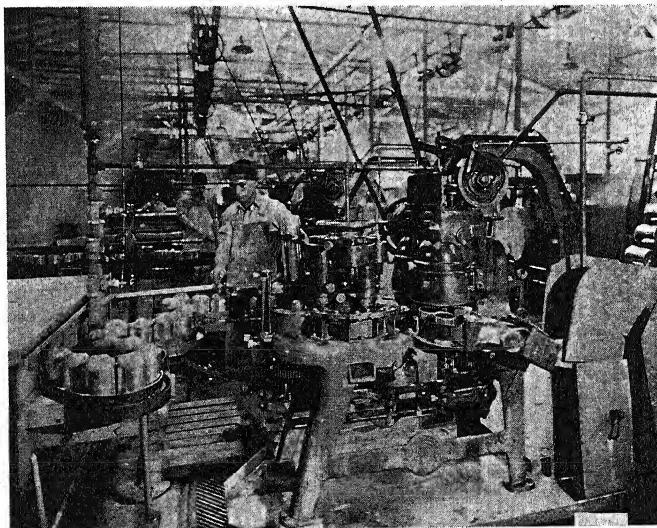


Fig. 55.—As the cans emerge from the exhaust box, they immediately pass into the capping machine which automatically seals as many as 90 cans per minute. (Courtesy National Canners Association.)

In some instances, the removal of the gas and air is accomplished by mechanical means. With this method, the cans are sealed in a chamber under a high vacuum.

The amount of vacuum in the processed, cooled container will vary with the size and style of the container and the product. Too high a vacuum in the larger can sizes will result in paneling, or a drawing in of the side of the can. With most products in the smaller or consumer size cans, a vacuum of 7-8 in. is adequate, but with corrosive foods this should be increased to 12-15 in. These higher values may be attained in the larger can sizes without distortion of the container by the use of beaded cans of selected dimensions.

6. Sealing

The cover is permanently sealed on the filled cans by a closing machine, or double seamer, which makes an interlocking seam between a flange on the can and the cover.

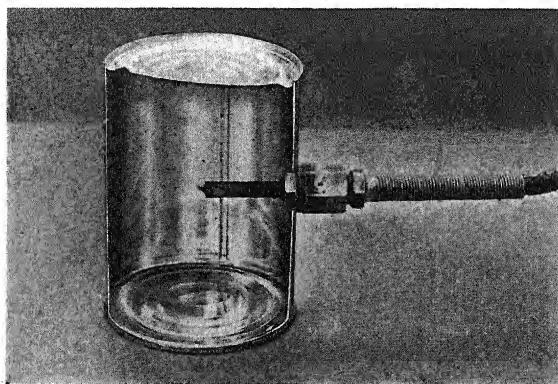


Fig. 56.—A cut-away can showing how the thermocouple is fitted for measurement of rate of heating. (Courtesy American Can Co.)

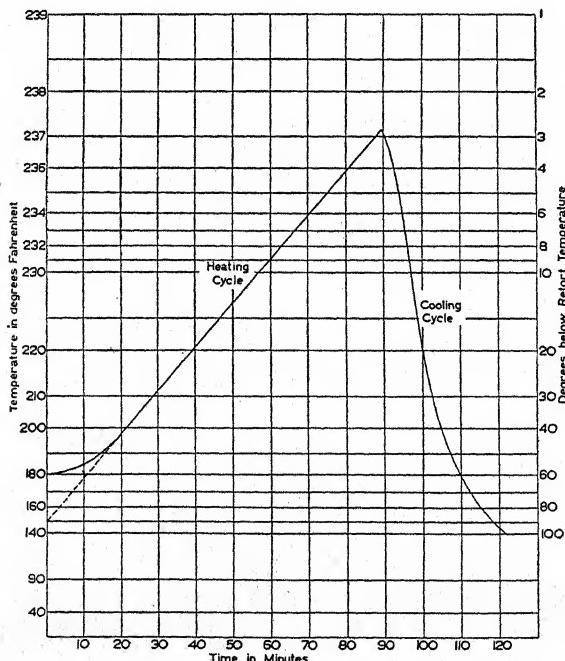


Fig. 57.—Heat penetration curve showing conduction heating. Convection heating will exhibit a more rapid attainment of maximum of temperature. (Courtesy American Can Co.)

See page 60. Hermetic closure is assured by a film of rubber compound, originally present on the cover, between the layers of metal.

Two other types of sealing are used for milk, which is not commonly canned in the open-top can used for fruits and vegetables. In one, the can is filled through a small opening which is then closed by solder tipping. In the other type, the can is filled through an opening about $\frac{3}{4}$ in. in diameter which is closed by seaming in place a tin-plate cap.

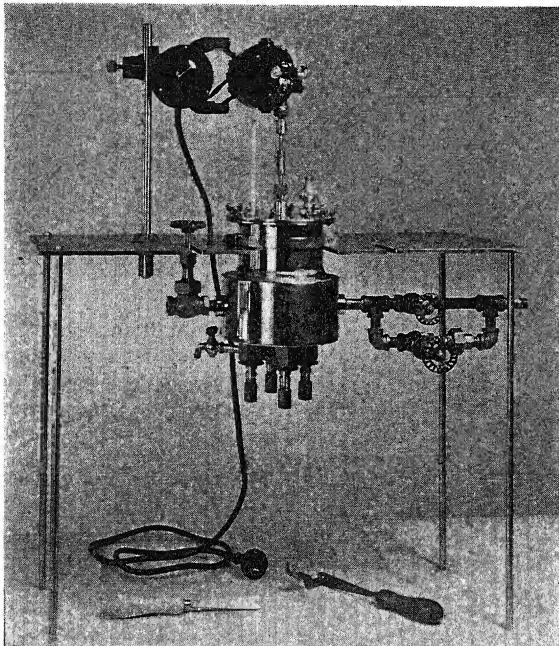


Fig. 58.—Heat-resistance apparatus for determining rate of destruction and thermal death time of heat-resistant spores. (Courtesy National Canners Association.)

Glass containers are closed by a machine which presses on a close-fitting cover carrying a rubber gasket.

7. Processing^{5a}

The term "process," as used in the canning industry, is synonymous with cook, and designates, in terms of temperature and time, the heat treatment given the permanently sealed container. The minimum requirement for the process for any product is that it be adequate to destroy the most heat-resistant organism likely to be present which, if not destroyed, would be a hazard to the health of the consumer. Other bacteria which are more resistant to heat may be present; and while these are not a

^{5a} For a more detailed discussion of the principles involved in process determination, see C. O. Ball, *Ind. Eng. Chem.*, 35, 71-84 (1943).

menace to health, they may cause spoilage if not destroyed. Thus the minimum process may not always be adequate to prevent spoilage; for this reason the process actually used is frequently greater than the minimum. The objective of the process is sterility of the contents of the container. Bacteriological sterility, although commonly attained, is not always essential or practicable. Hence there has come into use the term "commercial sterility," by which is implied the destruction of all organisms

which might develop under the commercial conditions normally maintained during storage of the food.

In the early days of canning, the process was empirical, and both the process and the method of processing were considered trade secrets. Scientists of the industry realized that, in order to place processing on a sound basis, it was necessary to know the rate at which heat travels to the coldest part of the can. It was also necessary to know the resistance to heat of the organisms which must be destroyed; and, since a portion of the time of heating up to the maximum temperature and of the time of cooling have lethal value as well as the maximum temperature, it was necessary to evaluate in terms of sterilizing efficiency the entire curve describing the heating of a product.

Although many measurements of heating were made by the use of maximum thermometers, ordinary thermometers sealed into the can through a stuffing box, recording thermometers, and other devices—all these suffered from a lack of accuracy or did not give complete information on

Fig. 59.—Sealed cans of food being lowered into a retort or pressure cooker for processing. (Courtesy American Can Co.)⁹

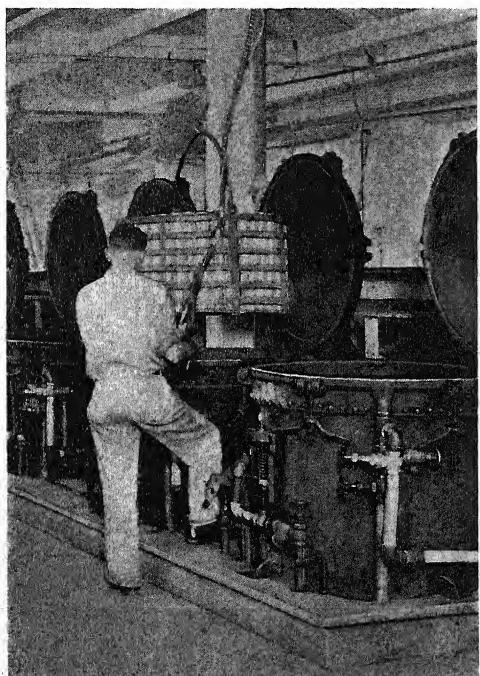
the change of temperature. The solution of heating was afforded through the development and adaptation by Bigelow and his colleagues⁶ of a thermocouple satisfactory for use in canned foods. Esty and Williams⁷ furnished a method which permitted accurate reproducible determinations of bacterial spore resistance to heat; and Ball⁸ supplied the mathematical correla-

⁶ W. D. Bigelow, G. S. Bohart, A. C. Richardson, and C. O. Ball, "Heat Penetration in Processing Canned Foods," *Bull. 16-L. Natl. Canners Assoc.*, Washington, D. C., 1920.

⁷ J. R. Esty and C. C. Williams, *J. Infectious Diseases*, 34, 516 (1924).

⁸ C. O. Ball, "Thermal Process Time For Canned Food," *Bull. Natl. Res. Coun.*, 7, Part 1, No. 37 (1923).

⁹ *Canned Food Reference Manual*. Section III, Chap. 2, American Can Co., New York, 1939.



tion of the physical measurements of the rate of heating and the bacteriological determinations of heat resistance.

The thermocouple is a copper-constantan couple enclosed in a Bakelite support and mounted in the can through a stuffing box. (See Fig. 56, page 346.) The wires leading from the couple are sheathed in asbestos and attached to a potentiometer, which may be calibrated in degrees or millivolts. By the use of the thermocouple it is possible to determine readily and accurately the rate of temperature change during processing and the effect of various factors on the rate. The curve which results from plotting the data observed is called the heating or heat penetration curve. (See Fig. 57, page 346.)

Determinations of the heat resistance of spoilage bacteria may now be made by one of several methods. That described by Esty and Williams⁷ consists of sealing a quantity of standardized spore suspension in a buffer solution in small glass tubes, heating in a thermostatically controlled bath, and at appropriate intervals removing a number of tubes (usually 5) and subculturing in a suitable nutrient. If the suspension is heated in a food or food juice, the tubes may be incubated directly. The Research Department of the American Can Company⁸ has developed a thermal death time can, which is used in place of the tube and is heated in a special thermal death time apparatus. A significant contribution to the study of thermal death time is to be found in the apparatus described by Williams, Merrill and Cameron.¹⁰ This is a steam-jacketed unit with valves which permit withdrawing a sample under aseptic conditions. (See Fig. 58, page 347.) It affords a ready method for determining rates of destruction as well as end points. If the end points arrived at by any method be plotted on semilogarithmic paper against the time required for destruction at several temperatures, with the time on the logarithmic scale, essentially a straight-line relationship between time and temperature is evident. (See Fig. 60, page 350.)

There are a number of factors which must be taken into consideration in arriving at a process time, either because of an effect on heat penetration or on spore resistance. Canned foods heat either by conduction or by convection, or both. Hence the consistency of the food influences to a high degree the rate at which heat moves into the center of the container. Also, the size of the container and the material of which it is made are of importance, because heat transfer is accomplished more quickly through a short distance and more readily through metal than glass. Likewise, the fill of the container and the size of the particle have an influence on the rate of heating. Pure steam has a higher temperature at equal pressure than does steam mixed with air, so adequate venting of the retort hastens the attainment of maximum temperature. The rate of heat transfer may be greatly accelerated in many products by the use of rotating or agitating cookers. With some products, because of a peculiar orientation of the product solids in filling, the position of the can in the retort during a still cook has been found to be significant. With the can in a horizontal position the heating curve may approximate conduction heating, while with a vertical position heating will be by convection.

¹⁰ C. C. Williams, C. M. Merrill, and E. J. Cameron, *Food Research*, 2, 369 (1937).

Bacteria show their highest resistance to heat destruction in the range of the neutral point. Consequently, in an acid or semiacid food there will be a more rapid inactivation of the organisms than in a low-acid product. Thus, for cut green beans, a convection heating product with a pH value of about 5.2, the recommended process is 20 min. at

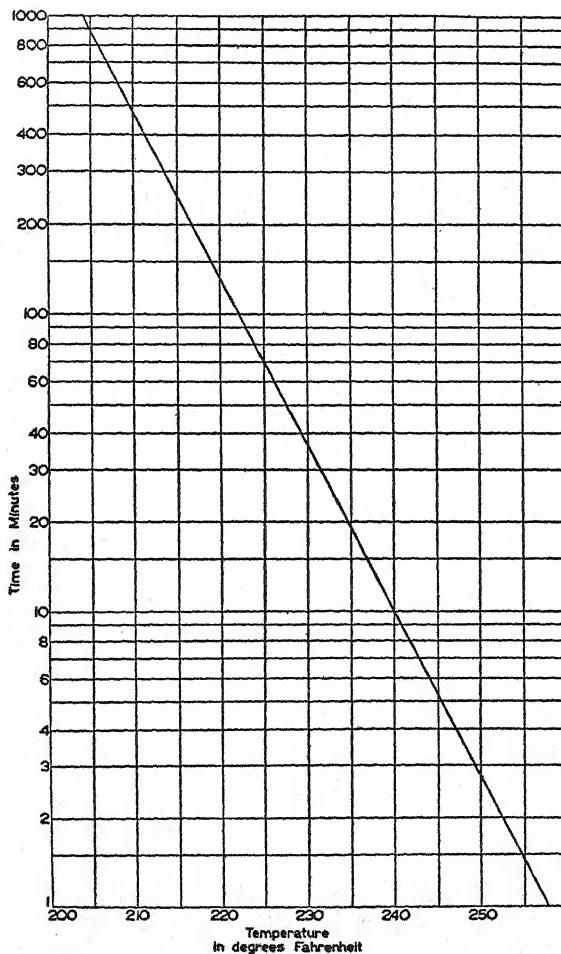


Fig. 60.—Thermal death time curve of spores of *Clostridium botulinum*. (Courtesy American Can Co.)^{10a}

240° F. for a No. 2 can, while for peas, another convection heating product, with a pH value of about 6.2, it is 35 min. The pH value of the acid foods (pH 4.5 or less) is too low for the growth of the bacteria concerned in the spoilage of the low-acid foods and is inimical to their existence. For acid products it is ordinarily sufficient to process

^{10a} Based on data of Esty and Meyer, *J. Infectious Diseases*, 31, 650 (1922).

under conditions which will insure the destruction of acid-tolerant microorganisms, and a maximum temperature of 190-200° throughout all particles of the food is usually sufficient. This may sometimes be accomplished by filling hot, sealing, and cooling without additional heat treatment.

In arriving at a process for a product, it is necessary to correlate the thermal death time of the particular organism to be destroyed with the rate of heat penetration, so as to obtain for the temperature of the process to be used a time which is theoretically adequate to destroy the organism if present in the slowest heating part of the can. The value obtained is termed the calculated process. As a safety factor the time which is just adequate is increased slightly to compensate for the possible presence of spores which may have a somewhat higher resistance than the test spores, and also for heavier contamination than would be considered normal.

Experience has shown that the calculated process is dependable; but it is customary to make an experimentally inoculated pack as a check. This involves the inoculation of a substantial number of cans, packed under operating conditions, with spores of a test organism. These are divided into lots, and processes given both above and below, as well as at, the calculated process, after which they are incubated and observed for spoilage. In lieu of incubation, mass cultures of the contents may be made. The process which is indicated by the results of such a pack is termed the experimentally derived process.

It is obvious that for any process time at a given temperature there is a shorter time at any higher temperature and a longer time at any lower temperature within the lethal range which has an equivalent sterilizing value. Low-acid foods are most frequently processed under pressure at 240 or 250° F.; and the choice of what time-temperature combination to use is governed by practical considerations. Glass containers are processed at the same temperatures as cans, but under water to facilitate heat transfer and distribution, and with superimposed air pressure in order to prevent the cover's being forced off by the pressure within the container.

With any food and under any circumstances, the minimum process is that which is consistent with safety and preservation. Desirable characteristics of flavor and texture may sometimes require a process in excess of that which will yield sterility. In general, though, overprocessing is avoided.

8. Cooling

The cooling operation consists of exposing the hot processed cans to a cooling medium for a period of time before casing and warehousing. Since a lethal temperature will persist for a fraction of this time, the operation is an integral part of the process. The time and method of cooling depend upon the cooling medium, the product, and the container. A slow loss of heat, which may be advantageous as a means of extending the process or in the production of desirable quality characteristics, is afforded by air cooling, in which the cans are stacked so as to allow a free access of air. The more common cooling medium, however, is water. With the large sized or irregularly shaped cans, and with glass containers, pressure cooling in the closed retort is

necessary in order to avoid an excessive strain on the container. This is done by a slow reduction of the pressure external to the can in order to balance the slow loss of pressure within the can. The small can sizes may be cooled in the retort at atmospheric pressure by shutting off the steam and admitting cold water. Another common method is immersion of the crates of cans in a cooling canal, or, less commonly, placing them under a spray head. The average temperature of the can at the end of the cooling period should be about 100° F., since enough residual heat to dry the can surface should remain in order to prevent rusting. This is especially important with electrolytic tin-plate and enameled steel can ends.

At the end of the heat treatment, the can contents are under pressure. While cooling, a vacuum develops. The container has a greater tendency to leak during cooling, especially if roughly handled, than at any other time. For this reason the cooling water should have a low bacterial content or else an occasional can will show spoilage.

9. Casing and Warehousing

The processed cans must not be cased hot, because the loss of heat by radiation from the cases is slow and the fireless cooker effect which results may be sufficient to cause stack burning, with some injury to quality. Also, favorable temperature conditions may be provided for the development of thermophilic bacteria which may have survived the process. Likewise, the cases should not be stored immediately adjacent to steam pipes. Freezing will not injure the nutritive value, but may affect the appearance of the food. Extremes of temperature during storage should be avoided. The warehouse should be well ventilated and held within a range of temperature which will prevent sweating, or the condensation of moisture, with consequent danger of external corrosion.

III. SANITATION AND WASTE DISPOSAL

Since the canning of most products is of necessity a wet operation, there is frequently a great deal of spillage of material. The factory should be so constructed that this can be promptly washed away. If allowed to accumulate, it interferes with efficient operation and constitutes a definite industrial hazard. For esthetic reasons as well, juices and refuse should not be allowed to accumulate. These are putrescible; and, unless there is scrupulous attention to the cleanliness of the surroundings, unpleasant odors will result.

In most instances, cleanliness is attained solely by the use of water, either hot or cold, and steam. At the end of a daily or half-day period of work, the equipment is scrubbed and steamed free of all traces of food residue and left as dry as possible. After an intermission, a thorough flushing of all the food handling machinery is desirable. Detergents, and such disinfectants as bleaching powder, may be necessary under some conditions or in the packing of some products; but, under any circumstances, steam and water under a pressure of at least 50-60 lbs. are essential for an efficient general cleanup. When chlorine compounds are used on equipment, a

thorough washing is of utmost importance because traces of chlorine may cause undesirable flavor changes.

After preparation of raw products for canning, there remains a large quantity of solids which are either inedible or unsuitable for use as food by human beings. Not all of this material is to be considered as waste, since much of it is utilized as a source of by-products or as food for livestock. The portion which has no commercial value is handled as garbage.

The washing and blanching operations and the maintenance of physical cleanliness in the factory require a large volume of water which becomes waste rich in soluble and suspended organic matter. The disposal of this waste water, which for many products will approximate 1 gallon for each No. 2 can packed, and for some may be much higher, is an acute problem and one which has been the subject of extensive study by a number of States. The peak of the canning season for most products comes during the summer months when streams are low and the amount of dissolved oxygen is at a minimum. Because of its high biochemical oxygen demand, cannery waste discharged directly into a stream will result in some depletion of the dissolved oxygen and may create a nuisance. Furthermore, it may bring the canner into conflict with Conservation Services because of an injurious effect on fish and possibly other wildlife. Many factories are located in small cities or villages where the municipal sewage plant is inadequate for treating the added heavy seasonal load of raw cannery waste. In a number of instances it has been necessary to install some type of pretreatment, which includes as the first step the removal of gross solids by screening. Where climatic conditions and soil permit, the liquid may be disposed of by lagooning or broad irrigation, but in most cases it is necessary to treat further by some one of the well-known methods of chemical precipitation, biological oxidation, or a combination of these, before final disposal.

IV. SPOILAGE IN CANNED FOOD

Bacterial spoilage of canned food may be the result of underprocessing, in which event spores of high resistance to heat survive the process and subsequently initiate growth; or it may be attributed to container leakage after processing. In rare instances, nonsporing organisms, chiefly lactic acid bacteria and yeasts, may survive in acid products which get a short boiling water process, or which are filled hot and not processed. In these cases, spoilage is due to the use of a low sealing temperature. If heat penetration is slow, even a fairly long boiling water cook may not raise the coldest part of the larger can sizes from a temperature which is sublethal to one which is lethal. This type of spoilage presents little difficulty in diagnosis, and the remedy is obvious.

Of greater importance and interest are the instances of spoilage because of heat-resistant spores, which are characteristically restricted to foods with a ρH above 4.5. Three groups of thermophilic and one group of mesophilic bacteria are of greatest concern as causal agents in this connection. The thermophilic types include: the aerobic flat sour group, of which *Bacillus stearothermophilus* is the type species; the aerogenic

anaerobe, *Clostridium thermosaccharolyticum*; and the nonaerogenic, hydrogen sulfide producing anaerobe, *Clostridium nigrificans*. The mesophilic group includes the putrefactive anaerobes and possibly, in very rare instances, aerobic spore formers.

1. Flat Sour Spoilage

Spoilage by the flat sour group of organisms is characterized by the production of acid without gas. The bacteria concerned are facultatively anaerobic; and while some are obligately thermophilic others grow over a wide temperature range. The spores produced, either in nature or in the laboratory, have a very high resistance to heat. The test strain, No. 1518, of the National Canners Association, in a concentration of 10,000 per ml. in neutral phosphate, for an extreme example, requires 50 min. at 250° F. for destruction. These bacteria are of greatest importance in the low acid foods, such as peas and corn. Since gas is not formed, the can remains flat. The product is not greatly changed in appearance but may have a faintly disagreeable odor. The final ρH is usually in the range of 4.2 to 4.5, but may sometimes be as high as 5.0. Microscopic examination of the food shows rod-shaped cells only, since spores are not formed in the presence of acid. Culturally, acid without gas in glucose broth incubated at 130°, confirmed by spore production on neutral medium, is diagnostic.

2. Thermophilic Gaseous Spoilage

The spoilage caused by the thermophilic aerogenic anaerobe is characterized by the swelling of the container, frequently to the point of seam rupture. The gas produced contains a large amount of hydrogen and will readily ignite. The food has an odor strongly suggestive of butyric acid. The organism, probably a single species, is obligately anaerobic and thermophilic, and is capable of growth in semiacid foods such as spinach and asparagus, as well as in the low-acid foods. The final ρH value is in the same range as flat sour spoilage. Microscopic examination shows long, slender, frequently granular, vegetative rods. Cultures in liver medium, stratified with nutrient agar, produce an abundance of gas. If neutrality is maintained in such cultures by the addition of calcium carbonate, spores will be formed.

3. Sulfide Spoilage

Spoilage by the obligately thermophilic, hydrogen sulfide producing anaerobe, *Clostridium nigrificans*, is not of frequent occurrence, but several outbreaks in low-acid foods have been noted. In this type of spoilage the can remains flat, and the contents have the odor of hydrogen sulfide and may be blackened. Diagnosis presents no difficulty. The organism may be isolated by subculturing the food in the special medium described by Cameron.¹¹

4. Putrefactive Spoilage

This type of spoilage occurs chiefly in the low-acid foods, although rarely outbreaks in semiacid foods, especially asparagus, have occurred. It is characterized by the

¹¹ E. J. Cameron, *J. Assoc. Official Agr. Chem.*, 21, 457 (1938).

swelling of the can, with the contents becoming putrid. Microscopic observation reveals rods and, commonly, spores. Cultures in liver medium stratified with nutrient agar show gas formation at mesophilic temperature. The cultures have a foul odor.

5. Unusual Types of Spoilage

Of the unusual types of spoilage there are two which have features making them of sufficient interest to justify brief discussion. One of these, flat sour spoilage in tomato juice, is an exception to the general rule that acid products are immune to spoilage by spore forming bacteria. This spoilage was of frequent occurrence in the early days of tomato juice manufacture, but under current methods of production and control is now rare. It is manifested by the development of a medicinal or phenolic flavor. The can remains flat, but there is a loss of vacuum. The juice drops slightly in ρH —from about 4.3 normally to about 3.7 to 3.9. Microscopic examination reveals large vegetative rods, but cultures are commonly negative since the organism is not long-lived in the acid environment, and spores seem not to be formed in the product. Diagnosis, therefore, is based upon microscopic and ρH determinations and the characteristic flavor change, which may at times be so slight as scarcely to be noticed. The causal organism, *Bacillus thermoacidurans*, was first isolated and described by Berry.¹² Certain of its peculiar growth characteristics in medium and juice have recently been noted by Stern, Hegarty, and Williams.¹³

A rare condition in which beets develop a black color has been recorded by Cameron, Esty, and Williams.¹⁴ The organism responsible, *Bacillus betanigrificans*, is an aerobic, mesophilic, spore former which requires the presence of small amounts of iron in order to develop the black color. Cultures on medium which do not contain both beet juice and iron do not become black. The writer has seen only one instance other than that noted above of this type of spoilage.

6. Leakage of the Tin or Glass Container

Spoilage as a result of a defect in the container is of lesser importance from a biological than from a mechanical standpoint. The organisms concerned are free-living, heterogeneous saprophytes, chiefly nonsporulating types which could not have survived the process and must therefore have entered the can after processing. In contrast to the microscopic and cultural observation of a single type in spoilage attributed to underprocessing, spoilage as a result of leakage shows a variety of organisms, including cocci and pleomorphic rods. Spores are rarely, if ever, seen. The can swells. The contents of different cans vary greatly in odor and appearance: Some are very frothy; others are slimy. The gas formed is chiefly carbon dioxide. The ρH values among different cans vary over a wide range. Growth in subcultures is rarely obtained except at 98° F. or lower, provided the inoculated tubes for incubation at

¹² R. N. Berry, *J. Bact.*, 25, 72 (1933).

¹³ R. M. Stern, C. P. Hegarty, and O. B. Williams, *Food Research*, 7, 186 (1942).

¹⁴ E. J. Cameron, J. R. Esty, and C. C. Williams, *Food Research*, 1, 73 (1936).

thermophilic temperature are preheated to about 130° before being placed in the incubator. This type of spoilage may be encountered in any product, and presents little difficulty of diagnosis even in the absence of pressure testing and seam examination of the faulty container. The variable pH, mixed flora on microscopic examination, and variation in appearance and odor of the product are highly characteristic. With acid products, some difficulty in deciding whether spoilage is due to leakage or to the use of a low sealing temperature may at times arise.

7. Autosterilization

Frequently cultures made from spoiled food fail to show growth, although the microscopic and organoleptic examinations leave no doubt that the spoilage was bacterial. Such a condition is termed "autosterilization," and is explained by the fact that the high acidity of the product exerts a sterilizing action on the spoilage organisms.

V. ORIGIN OF SPOILAGE BACTERIA IN NATURE

The bacteria concerned in the spoilage of canned food are probably at home in nature in the soil, but rarely enter the factory on the raw product in sufficient numbers to constitute a spoilage hazard. The work of Cameron and his collaborators¹⁵ has demonstrated certain critical sources of these organisms so far as canned food is concerned. The earliest work in this connection established the importance of sugar and starch as carriers of spoilage spores in excessive numbers. The significance of this work was promptly recognized by the manufacturers of sugar and starch, and methods of manufacture were so changed that a product of low bacterial content was made available. Subsequent work showed wooden brine tanks and various items of machinery, such as pumps, mixing and blending tanks, blanchers, and pipe lines, to be foci of contamination at times. There is no question that the organisms originally entered the factory in low numbers on the raw product or in an ingredient, and became established in a favorable location. Once present they are almost impossible to dislodge because of their resistance to the concentrations of disinfectants and the temperatures which can be used. With none of these foci is the bacteriological condition a consequence of a lack of physical cleanliness. Food requirements for some growth of the organisms apparently can be met by the water used in cleaning up, and since some water will inevitably be left in and on the machinery, growth will occur if environmental conditions are suitable.

Control then becomes a matter of rendering the environment unsatisfactory for growth. The manner of accomplishing this depends upon the organism and the equipment in question. With thermophilic bacteria, for example, it means keeping the temperature too high, or too low, for growth during nonoperating periods. As an added precaution, all machinery coming in contact with the food should be thoroughly

¹⁵ E. J. Cameron, C. C. Williams, and R. J. Thompson, "Bacteriological Field Studies in Canning," *Bull. 25-L. Natl. Canners Assoc., Washington, D. C.*, 1928.

flushed with a large volume of water just before operations start. This serves to wash off most of the bacteria and thereby bring the level of contamination below that which would constitute a spoilage hazard.

Repeated bacteriological survey tests have established that the level of contamination, when contamination exists, is highest at the start of operations after a shutdown period, such as overnight or for lunch. As a control on the bacterial condition of the factory, many packers run incubation tests on the first few cans filled after an intermission. These may even be given a process somewhat less than the regular process, on the basis that if the bacterial load is not heavy enough to cause spoilage in deliberately underprocessed cans, it will not cause spoilage in cans receiving the full process.

VI. STANDARDS FOR CANNED FOOD

Under the Federal Food, Drug, and Cosmetic Act which became effective on June 25, 1939, the Secretary of Agriculture was empowered to promulgate minimum standards of quality and fill of container and, after public hearings, to establish definitions and standards of identity for canned foods entering interstate commerce. When a definition and standard of identity has been promulgated for a canned food, any deviation from it is forbidden. For those which have not been defined and standardized, a list of ingredients must appear on the label. Foods which for any reason do not conform to the minimum quality requirements must carry a substandard legend. The enforcement of this act is the responsibility of the Food and Drug Administration of the Federal Security Agency. Some of these standards are listed on pages 156 *et seq.*

Meats and meat food products were exempted from the provisions of the Food and Drug Act to the extent of the application of the Meat Inspection Act. These are still prepared under the mandatory supervision of inspectors operating under the provisions of the Meat Inspection Act of 1907, as amended. These products must conform to the standards of wholesomeness and sanitary methods of preparation specified by the Livestock and Meats Division, Food Distribution Administration (Bureau of Animal Industry), which has responsibility for the enforcement of the act. Upon request, a comparable optional continuous inspection service is provided for shrimp by the Food and Drug Administration, and for poultry and poultry food products by the Food Distribution Administration. Through the inspection of the raw product afforded by these services a high standard of canned product is assured.

The Food Distribution Administration also provides an optional continuous inspection service for fruits and vegetables. Commodities packed under this service may add the prefix "U. S." to the designation of the grade of quality assigned, in accordance with the standards issued by the Department of Agriculture. The grading service for quality is available to any canner, whether operating under inspection or not. Samples are graded by official inspectors upon a scoring system, with points assigned to the principal factors determining the quality of the product, and an official certificate of grade is issued.

VII. LIFE OF CANNED FOODS

The question of how long a canned food will remain in a wholesome condition is of interest to both consumer and producer. The answer rests upon the life of the container since, with possibly a few exceptions, if there were no action of the food upon the interior and no external corrosive action, the food would remain unchanged indefinitely. The major physical factors determining can life include the sealing temperature, the head space, the type of plate and weight of the coating, and the storage temperature. Since most canned foods are on the acid side of neutrality, there is possible a slow action on the container of the food acid with some solution of tin and iron, which may be accompanied by the liberation of hydrogen gas, in which event the can will eventually develop internal pressure. The problem is not one wholly of acid-metal reaction, because some products attack the metal more rapidly than can be accounted for on the basis of acid alone. Certain of the pigmented fruits, for example, have a much shorter container life than do other fruits of equal or greater acidity. With some foods, such reaction as does occur is very slow. The writer examined, in 1936, a can of corn packed in 1895 which showed only a very slight internal pressure and which was bacteriologically sterile and in good condition.

The changes which take place in the food during storage do not constitute a health hazard. Drummond and Lewis¹⁸ have reported feeding experiments in animals with canned tripe about 48 years old and canned veal 114 years old. They also record the consumption by human beings of canned meat which was 20 years old and of pea soup and beef which were 87 years old, all without ill effects. It is of interest that vitamin determinations on certain of these very old canned foods showed a substantial retention. The ages of these foods were extreme; but the results serve to emphasize that the determining factor in deciding upon edibility should be the condition of the container and the food and not the length of time elapsed between packing and consumption.

VIII. CANNED FOOD IN RELATION TO HEALTH

The relation of any food to the health of the consumer involves two main considerations: the nutritive value, and the toxicological aspects.

1. Nutritive Value

So far as the nutritive value of canned food is concerned, present information indicates that all requirements of an adequate diet can be met by the use of a variety of canned foods. Animals have been carried through several generations on a diet composed exclusively of canned food with no evidence of any dietary deficiency. This does not imply that a single canned food will afford a complete diet. Any one food can supply only a limited number of the substances essential to normal life. Hence a reasonable variety is necessary, and a wide variety affords a valuable safety measure.

¹⁸ J. C. Drummond and W. R. Lewis, *Historic Tinned Foods, Part I, Historical Introduction*. International Tin Research and Development Council, Middlesex, England, 1939.

A matter of great interest in any consideration of the nutritive value of foods is that of vitamin retention. The stability of vitamins under the various conditions of producing and handling food incident to human consumption is still the subject of very active investigation. The available evidence indicates that the procedures used in commercial canning give a high degree of retention, and that canned food may be stored for long periods with little or no loss of vitamin content.

2. Toxicological Aspects

Referring now to the toxicological aspects of food, if there be excluded from consideration poisoning attributed to the consumption, as food, of a naturally poisonous plant or animal, cases of illness may arise from the ingestion of food contaminated either with a toxic chemical or with pathogenic microorganisms. So far as commercially canned food is concerned, the experience of the canning industry justifies the statement that neither of these factors is of practical importance in connection with its products.

The metallic salts which may be present in canned food are those which can be acquired from contact of the food with the food handling machinery and the container. These are almost exclusively tin and iron. The quantity of these will vary somewhat with the food, but in all cases is small and without health significance.

The industry recognized the theoretical possibility of lead contamination from solder which sometimes creeps through the soldered side seam to the interior of the can during fabrication. Through extensive experimentation it has been shown that no health hazard is created by this action. Improvements in canning technology which have eliminated lead bearing surfaces within the plant, combined with modern can manufacturing practice, assure complete safety from toxic amounts of this objectionable metal.

In combating insect pests, various sprays, some of which may be toxic, are frequently used on fruits and vegetables during the growing season. Sprays are rarely used just before the harvesting of the product, and where rainfall is abundant are generally absent from the surface of the product at the time it is harvested. Any spray residue which may still be present at the time of harvesting will be removed by the thorough washing given the product in preparation for canning.

Cases of illness due to food-borne pathogenic organisms are of much more frequent occurrence than those due to the ingestion of food-borne toxic chemicals. Among the food-borne pathogenic bacteria there is only one of such resistance to heat as to be of significance in canning—namely, *Clostridium botulinum*. The *Salmonella* group and the food poisoning *Staphylococci* and *Streptococci* are at home in nature in the body of an infected animal or human being. Under commercial conditions of canning there is, then, little or no opportunity for them to be present on the food; and because of their low resistance to heat there is no possibility of their survival in the canned product even if they should be present. Canning experiments with a food poisoning strain of *Staphylococcus aureus* have shown that this organism, even when planted deep in

tissue of the particle size used in canning, will not survive five minutes at boiling temperature in low-acid foods. The organism dies out rapidly in acid foods even at room temperature. Furthermore, the toxin produced will not survive the process. Gastroenteritis from canned food then can be explained only on the basis of an infection of the food after opening.

Reports in the press of occasional outbreaks of botulism as due to canned food have very generally failed to include the salient information that inadequately processed, home-canned food was the responsible cause. Before processing was firmly established on a scientific basis there were a few outbreaks of botulism due to commercially canned food; but the cooks in use at present are more than adequate to destroy the spores of the causal organism. The effectiveness of modern processing practice is best attested to by the fact that there has been no case of proved botulism associated with food commercially canned in the United States since 1925. So far as is known, no case attributed to home-canned food processed in accordance with the schedules recommended by the Department of Agriculture in *Farmer's Bulletin No. 1762* has been recorded.

IX. HOME CANNING

Home canning does not differ in any regard from commercial canning so far as the fundamental principles are concerned. Adequate processes do not necessarily agree in time and temperature with those recommended for commercial canneries, but this is due to a difference in method of processing in home canning. The sterilizing value is equivalent.

Low-acid and semiacid foods should be given a pressure cook in accordance with the more recent schedules recommended by the Department of Agriculture or some other equally reliable agency. A boiling water or oven process for other than acid foods carries both a spoilage and a health hazard unless the time is so long that the process is no longer practical.

X. FALLACIES ABOUT CANNED FOODS

There are at least two widely prevalent lay opinions regarding canned foods which are without scientific or other foundation. One is that food left in the open can rapidly acquires poisonous properties. This idea seems generally to exclude milk, since it has long been customary to punch a hole in the milk can and use the milk, frequently without refrigeration between times, until the can is empty. With other products, however, the food is assumed to develop "ptomaines," or some ill-defined and toxic principle, unless promptly emptied into another container, which may be of the same metallic composition as the can. This belief has sometimes been supported by the attending physician in cases of illness presenting the classical symptoms of nausea, vomiting, and diarrhea, either because of a lack of knowledge or as a convenient diagnosis readily acceptable to the patient.

There are some foods which should be emptied from the container shortly after

opening, but not because of any danger to health which will result from a failure to do so. Certain pigmented fruits may lose color if held in the can, and a number of acid products are corrosive in the presence of oxygen. These will attack the container and, unless used within a few days, may become astringent and changed in flavor because some iron is dissolved. For most canned foods, the can is the best container for an unused portion of the food because it was at least sterile at the time of opening, while a dish or pan is likely to serve as a source of bacteria which will find in the food a suitable environment for growth. The point of greatest importance is treating the exposed food as a perishable product. The container in which it is held is of minor significance.

The other common erroneous opinion about canned food is that toxic amounts of tin may be present. Feeding experiments with relatively large amounts of tin have shown that this metal in the smaller amounts present in canned food is not productive of harmful effects.

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<i>Canning Age.</i>	<i>Food Manufacture.</i>
<i>Canning Trade.</i>	<i>Food Research.</i>
<i>Food.</i>	<i>Fruit Products Journal.</i>

Analytical Procedures will be found in *Official and Tentative Methods of Analysis of the Association of Official Agricultural Chemists*, and in the *Journal of the Association of Official Agricultural Chemists*, both published by the Association, Washington, D. C.

Chapter XII

FOOD PRESERVATION BY USE OF MICROORGANISMS

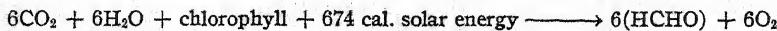
F. W. FABIAN

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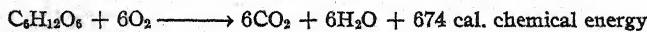
The primary role which microorganisms play in the universe is that of destruction. In the cycle of elements of the organic universe the chlorophyllaceous plants utilize the elements, carbon, hydrogen, nitrogen, phosphorus, and sulfur, to form complex substances; the nonchlorophyllaceous plants, such as bacteria, yeasts, and molds, break down these complex compounds into simpler substances. There are exceptions to this general scheme, *e. g.*, the symbiotic and nonsymbiotic fixation of nitrogen by the nitrogen-fixing bacteria and of sulfur and iron fixations by bacteria utilizing sulfur and iron. However, on the whole, plants built up the organic world and micro-organisms tear it down. Animals are not necessary in this cycle, and are usually shown as a side reaction in the cycle of elements.

I. FOOD AS A SOURCE OF ENERGY FOR MICROORGANISMS

Microorganisms break down organic compounds to obtain energy and food for growth and repair. By far the greatest amount of the compounds which they decompose is for their energy requirements. When chlorophyllaceous plants synthesize carbon dioxide and water by aldol condensation into higher carbohydrates such as dextrose, they build energy into the dextrose molecule. This is chemical energy which has been transformed from solar energy (light and radiant) to chemical energy by means of the chlorophyll's acting as a catalyst within the plant cells. Since micro-organisms have no chlorophyll to make solar energy available to them, they must get it in another and different way than do the green plants. They accomplish this by tearing down the compounds which have converted solar energy into chemical energy. Thus, all forms of life are dependent on the sun, either directly or indirectly. This relationship may be expressed empirically as:



When microorganisms completely decompose dextrose, the equation is reversed, and the energy released to them as chemical energy, thus:



II. MICROBIAL FOOD PREFERENCES

Plants and animals, which form the principal sources of food for microorganisms, contain, in addition to carbohydrates, proteins, lipids, minerals, vitamins, and vitamins. Generally speaking, the order of microbial preference of the three main foods is carbohydrates, proteins, and lipids. This does not mean that they do not use the latter two foods. Nor does it mean that they use carbohydrates in preference to proteins or lipids to obtain more energy, since fats and amino acids yield more energy per gram than carbohydrates. For example, some of the amino acids, such as leucine, tyrosine, and glutamic acid, yield more energy per gram than does glucose.

As a matter of fact, microorganisms have food preferences among carbohydrates themselves. The order of preference in general is:

- (a) Sugars: monosaccharides such as arabinose, dextrose, levulose, and mannose; disaccharides such as maltose, sucrose, and trehalose; and trisaccharides such as raffinose (melitose) and melezitose.
- (b) Alcohols: trihydric alcohols such as glycerol; and hexahydric alcohols such as sorbitol and mannitol.
- (c) Compounds like tartaric, succinic, and benzoic acids; monohydric alcohols such as ethyl and propyl alcohols; and fatty acids such as acetic and propionic acids.

There are some exceptions to the above, however, since compounds like xylose, galactose, lactose, and dulcitol are not readily utilized by most microorganisms. Certain groups such as the coliform and lactic acid bacteria and some few other bacteria, as well as a few species of yeasts and molds, can utilize these compounds readily. The commonly accepted reason for the failure of most microorganisms to use these compounds is that some molecular rearrangement of their chemical configuration is necessary, presumably by enol-keto tautomerism, before they can be fermented. Microorganisms capable of making this change can utilize them.

Since energy is such an important consideration with microorganisms, the value of organic compounds as a food for them seems to depend mainly, but not exclusively, upon the heat of combustion of the respective compounds. It appears that carbon is in its most available form when linked with hydrogen in the form of CH_2 , less available when linked as in CH , still less so as in CHOH , and not at all as in CO or CN radicals. For example, when carbon is linked to oxygen by two valencies as in urea, $\text{O} : \text{C}(\text{NH}_2)_2$, or as in oxalic acid, $\text{O} : \text{C}(\text{OH}) \cdot (\text{HO})\text{C} : \text{O}$ or by three valencies to nitrogen as in the cyanogen compounds, $-\text{C} : \text{N}$, it is useless as a source of carbon for most bacteria.

III. TYPES OF SUGAR FERMENTATION

There are six different ways by which microorganisms commonly ferment sugar. These will be discussed briefly because they have an important bearing on food preservation.

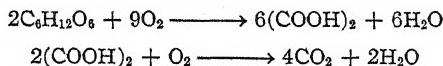
1. Complete Oxidation

Many bacteria, most molds, and a few yeasts completely break down a sugar like dextrose to carbon dioxide and water:

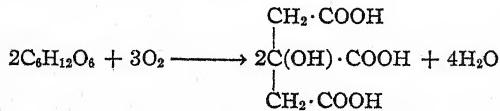


2. Partial Oxidation

This is by far the most common type of oxidation and is of value in both the food industry and the chemical industry, since it is by controlling this type of fermentation that desirable chemicals may be produced. Frequently, the intermediate products are completely oxidized, either by the same organism or by different organisms, unless the process is carefully controlled. *Aspergillus niger*, for example, will, if placed in a sugar solution, oxidize the sugar to oxalic acid, which can be precipitated by the addition of calcium hydroxide. If, however, the mold is allowed to remain in contact with the oxalic acid, it will oxidize it to carbon dioxide and water. The following equation will give some idea of the reaction:



Another example of this type of fermentation is in the production of citric acid by *Citromyces*. This mold oxidizes sugar to citric acid and water. An approximation of the reaction may be indicated as follows:



3. Alcoholic Fermentation

Certain industrial yeasts are the most efficient producers of alcohol. Many species of true and wild yeasts as well as bacteria and molds produce some alcohol; but the yield is low as compared with that of certain strains of industrial alcohol yeasts such as *Saccharomyces ellipsoideus*. Furthermore, in addition to alcohol, these other organisms produce products like aldehydes, acids, higher alcohols, esters, etc., from which it is hard to free the alcohol. The biochemical reaction is a complicated one, but the principal by-products of the reaction may be indicated as:

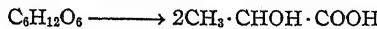


4. Lactic Fermentation

This type of fermentation is one of the most important in the food industry, since it plays an active part in the preservation of many foods, as will be shown presently. The organisms causing lactic fermentation are widely distributed in nature and are present on all foodstuffs such as vegetables, fruits, meats, and dairy products. They

have the ability to withstand adverse conditions which inhibit the growth of or entirely eliminate many other apparently hardy organisms.

The lactic acid bacteria also possess another advantage over many other groups of bacteria in that they convert the sugars into lactic acid without the formation of any other useless products. Members of this group important in food preservations are *Lactobacillus cucumberis* found in practically all vegetable fermentation, such as in kraut and pickles, *Streptococcus lactis*, *Lactobacillus bulgaricus*, and *L. casei* found in milk and dairy products. Although the biochemical mechanism by which lactic acid is produced from sugar is a complicated one, a simple chemical equation representing this type of fermentation may be written as follows:



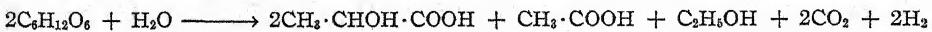
5. Gassy Fermentation

This likewise is a very important type of fermentation and is as common in foods as is lactic fermentation. There are a great variety of bacteria and yeasts capable of producing gassy fermentation. On the whole, this type is not so desirable as lactic fermentation because the evolution of gas may prove a nuisance under certain conditions. Also, it is not biologically as economical a fermentation as lactic because some of the products, as hydrogen and carbon dioxide, have little or no preserving value. Bacteria causing spoilage, besides those producing substances having a preserving action on foods, are found in this group.

Organisms producing a gassy fermentation in vegetables are *Leuconostoc mesenteroides* and *Lactobacillus pentaceticus* found in fermenting kraut. The sugars, glucose and fructose, are broken down to acids, alcohols, and carbon dioxide. Similar fermentations are found in ensilage. The principal end products are:



The coliform group, which is widely distributed in nature, will produce a gassy fermentation when there are plenty of minerals present. The principal representatives of this group are *Escherichia coli* and *Aerobacter aerogenes*. They may be found in fermented foods such as vegetables, salt rising bread, meats, and dairy products. The chemical equation representing the principal products formed may be written thus:



In the absence of sufficient mineral food, the coliform group may produce mainly lactic acid.

6. Butyric Fermentation

The organisms producing this fermentation are principally anaerobic. Butyric fermentation is undesirable in foods, since the products produced cause off-flavors and possess little or no preserving action. Furthermore, butyric acid is produced by disease-producing bacteria like *Clostridium tetani* and the food poisoning organism, *C. botulinum*. It is a very complicated fermentation, taking place in at least three

different stages. In addition to butyric acid, hydrogen and carbon dioxide, acetic acid and, in some cases, ethyl and butyl alcohols are produced. The final stage of the fermentation may be indicated:



IV. OTHER FERMENTATIONS

There are many other fermentations taking place in foods which influence their flavor, texture, and keeping qualities. This is true for carbohydrates as well as for proteins and the lipids. However, if the proteins and lipids are decomposed by microorganisms to any great degree, the food is spoiled rather than preserved. The preserving action of organisms in food is due mainly to the products which they produce as a result of the decomposition of the simple soluble carbohydrates present. The texture, the flavor, and the keeping quality of foods are all injured by organisms attacking the higher carbohydrates like cellulose, the hemicelluloses, pectin, and starch.

Ropy fermentation is of interest because it occurs in a variety of foods, and causes considerable trouble in many food industries. Ropy milk is caused by any one of several organisms, *Aerobacter aerogenes*, *Streptococcus hollandicus*, *Lactobacillus casei*, *L. bulgaricus*, *Escherichia neapolitana*, and *Alcaligenes viscosus*. Sugar factories are troubled with "frog spawn" due to *Leuconostoc mesenteroides*, which inhibits crystallization of the sugar from the liquor. *A. aerogenes* causes ropiness in maple sirup.¹ During the fermentation of salt stock pickles, the brine frequently becomesropy,² a condition which disappears within a few days if the salting schedule is maintained or slightly increased.

V. FACTORS INFLUENCING THE TYPE OF DECOMPOSITION

Microorganisms are widely distributed in nature both as to numbers and kind. Most foods are more or less in intimate contact with the soil from which they are produced and the soil is teeming with millions of organisms. Most favorable to any given type of fermentation are certain conditions, a slight change in which is most likely to produce another type of fermentation, which in turn may spoil the food. The factors most likely to influence the type of fermentation will be discussed briefly.

1. Acidity

All vegetables are acid in reaction, the degree of acidity depending upon the vegetable. The *pH* value of vegetables ranges from 6.3 for corn to 4.9 for okra. Likewise, all fruits are acid in character, ranging from *pH* 4.2 for tomatoes to *pH* 2.9 for plums. Meat such as beef is slightly alkaline in reaction (*pH* 7.2) when first slaughtered, the reaction then rapidly changing until it reaches a *pH* of 5.7 within 48 hours or so,

¹ F. W. Fabian and H. H. Buskirk, *Ind. Eng. Chem.*, 27, 349 (1935).

² F. W. Fabian and A. L. Nienhuis, Michigan Agr. Expt. Sta., *Tech. Bull.* 140 (1934).

gradually stabilizing at pH 6 within a week in the absence of microbial action. This is due to the change of glycogen into lactic acid in the tissues of the animal after death.

The two most common types of fermentation in an acid food are oxidation, either complete or incomplete, and alcoholic, depending upon the type of organisms which grow in an acid medium and their action upon the substrate. For example, molds and yeasts grow best in an acid medium such as is found in fruits and fruit juices and, therefore, soon predominate: We find apple and grape juice undergoing an alcoholic fermentation and fruits being rotted by molds. The type of acid present in the fruit or food frequently determines the type of mold present. For example malic, tartaric, and citric acids favor the growth of penicillia and aspergilli while lactic acid favors the growth of *Oospora lactis*. The general exception to bacteria not thriving in acid foods are the acetic bacteria, like *Acetobacter aceti* which thrives in such foods, and certain bacteria in wines.

On the other hand, normal fresh milk which is only very slightly acid in reaction (ranges from a pH of 6.5 to 7.2, with 80% of the samples under pH 7.76) undergoes a lactic or gassy fermentation under normal conditions.

2. Type of Carbohydrates

Microorganisms in general attack the soluble carbohydrate portion of the food first. This does not mean that they do not use other components of the food such as protein, since it has been shown that protein and other compounds in the food besides carbohydrates are decomposed. However, as previously pointed out, the carbohydrate portion, as for example, sugars, is readily available as food, the products produced from it by organisms being present in such abundance that these products dominate the picture. For example, milk normally sours because the bacteria usually found in milk attack lactose more readily than the other components, producing lactic acid, a reaction which in turn inhibits the growth of proteolytic and lipolytic bacteria. As soon as the lactose, and the lactic acid produced from it by bacteria, have been used up by *Oospora lactis*, the proteolytic bacteria gain the ascendancy and putrefy the milk, reducing the proteins to amino acids and finally to ammonia, hydrogen sulfide, sulfites, sulfates, phosphates, water, and carbon dioxide. When they have finished, the milk fat will be attacked by the lipolytic bacteria which reduce the fats to glycerol and fatty acids, which in turn are decomposed to carbon dioxide and water. Thus we may have a sequence of action by microorganisms which eventually reduces the milk to simple compounds.

3. Moisture

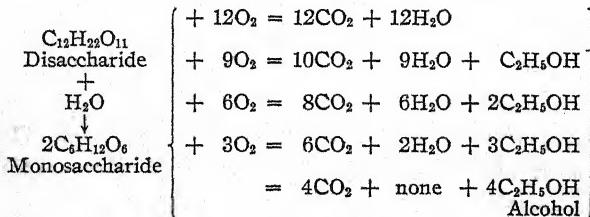
The amount of moisture present in food is another important factor, and determines not only the ability of organisms to grow but also the kind which will be present on food. Molds will grow on food materials if the moisture content is as low as 2%. Yeasts and bacteria, however, require a great deal more moisture, growth practically ceasing when the moisture content reaches about 30 to 40% in colloidal solutions. Foods present some excellent illustrations of the influence of moisture in preservation.

For example, fruit juices and fruit purees will undergo alcoholic fermentation but, when concentrated to jellies or jams by the addition of sugar and boiling, will mold unless properly protected. Vegetables high in protein, like peas and Lima beans, and meat and fish of all kinds undergo putrefaction when their moisture content is high. When dehydrated or smoked, unless kept in a dry atmosphere or otherwise protected, they mold. Molds will quickly spoil dry milk, but normal milk undergoes lactic fermentation. These foods mold, regardless of composition, because of lack of competition from organisms requiring a higher moisture content for development.

4. Oxygen

The presence or absence of oxygen, and even the amount of oxygen present, is one of the chief determinants of the type of biochemical reaction which microorganisms will produce in a food. In the presence of plenty of oxygen, certain substances are completely oxidized: Sugar is oxidized to carbon dioxide and water; amino acids to ammonia, carbon dioxide, and water; and fats to carbon dioxide and water. If the oxygen concentration is lowered somewhat, more intermediate products and less end products are produced by microorganisms. The action of microorganisms on sugar under these conditions results in the production of alcohol, lactic, acetic, and formic acids, of hydrogen, and of carbon dioxide. Proteins are broken down to amino acids with some formation of ammonia, hydrogen sulfide, sulfites, carbon dioxide, and water. Fats are likewise partially decomposed to glycerol and the higher fatty acids, with little or no carbon dioxide and water. When anaerobic conditions prevail, vile-smelling compounds are formed, as butyl alcohol and acid from sugar, the mercaptans and hydrogen sulfide from proteins, and the acetone bodies from fats. Because of the odor and nature of such intermediate compounds the decomposition is called putrefaction.

An excellent example of the influence of oxygen on the type of products formed is in the case of the alcoholic fermentation of sugar by yeasts. This relationship can be illustrated by chemical equations, as follows:



In beer and wine making and in the production of industrial alcohol, a limited amount of oxygen is both desirable and necessary for the vigor of the yeasts and the conversion of the sugar into alcohol. When, however, a large quantity of yeast is the goal rather than alcohol, as for food, yeast cakes, vitamins, and the like, the oxygen content of the medium is increased by aeration. In this way, the sugar is completely oxidized, yielding a great deal more energy per gram than under partial anaerobic conditions, and likewise a correspondingly greater yield of yeast cells.

The amount of oxygen not only influences the type and amount of products produced, but also the amount of food consumed and the energy released in the decomposition. Thus, in the case of sugar fermentation by yeasts, if the sugar is completely broken down, as:



or when only partially broken down, as:



there is a big difference in the type of products formed and energy released. Therefore, when yeasts are grown anaerobically, they consume approximately 30 times more food to obtain the same amount of energy as when grown aerobically.

Molds do not grow in the absence of oxygen so that, under anaerobic conditions, they are not a factor. A good example of the influence of air is in ensilage. If the ensilage is well packed in the silo, it will undergo principally lactic and gassy fermentations. If it is loosely packed, there will be only a small amount of these fermentations and the ensilage will mold instead.

5. Structure of Material

Most plant foods have a very definite structure. They also have an outer protective layer or epidermis which is usually tough and coated, in the case of fruits, with a waxy substance or, in the case of vegetables, with a mucilaginous substance. Animals and fish likewise have their protective outer layers. The ancients recognized this and had the adage, "A pin prick is the open door to death." The protective influence of the structure of foods is well illustrated in the case of fruits. Apples, for instance, will keep much longer if they are not bruised; if bruised or punctured, they rot. This is usually caused by a mold. When the cell structure of the apple is crushed and the juice expressed, the juice immediately undergoes alcoholic fermentation. One of the reasons why milk spoils so rapidly is because of its lack of a definite structure.

Another reason why fruits, vegetables, and meat keep well, as a rule, until their structure is crushed is attributed to their minimum exposure of surface area. The greater amount of area exposed, the quicker will the microorganisms attack the food. Ground meat, like hamburger, will spoil much sooner than a similar piece of unground meat because of the additional exposed surface area. This is true of many other foods, as, for example, sweet pickles and relish; the latter must have a higher acidity than the former to prevent spoilage.

6. Temperature

Physiologically, all microorganisms may be classified into three groups: cryophilic, mesophilic, and thermophilic. Each group has a maximum temperature for growth, the temperature ranges being given in Table 30. There is some overlapping between the groups, as the maximum and the minimum temperatures merge to a certain de-

gree. To obtain maximum food preservation from any particular group, the food should be placed at the optimum temperature of that group. This is well illustrated in kraut making. The optimum temperature for *Leuconostoc mesenteroides*, which initiates the fermentation, is 77° F., while that of the two subsequent groups, *Lactobacillus cucumberis* and *L. pentaceticus*, which complete it, is 86° F. If the temperature is too warm, so that the latter groups initiate rather than complete the fermentation, kraut of inferior flavor and quality results.

Thermophilic bacteria, when present, cause trouble in canned food if it is not properly cooled or if it is stored in a hot place or shipped to a hot climate. Canned meat to which have been added supplementary products like soybean flour is very hard to sterilize and keep because of the thermophilic bacterial content of the added products. Much of the canned food shipped to the tropics is subjected to temperatures which are optimum for thermophilic bacteria.

TABLE 30
TEMPERATURE RANGES FOR MICROORGANISMS

Type of bacteria	Min., ° F.	Opt., ° F.	Max., ° F.
Cryophilic	32	59	86
Mesophilic	59	98.6	113
Thermophilic	113	131	158

The change taking place in milk at different temperatures is another excellent example of the influence of temperature on food preservation. Milk kept at -15.8° F. (-9° C.) eventually develops an abnormal flavor. At 32° F., there is no multiplication of bacteria, but usually a decrease with a gradual dying off. The milk, however, develops an abnormal flavor, with some clumping of casein at the end of approximately a month. At the end of three months, gas formation occurs, as well as a bad odor and a digested appearance. Milk held at 40° F. (4.4° C.) undergoes essentially the same changes as at 32° F., but within a shorter time. Bitter andropy fermentations are prevalent at 50° F. (10° C.), since the bacteria causing these changes grow best at this temperature. As the temperature of the milk is raised to 70° F. (21.1° C.), a typical lactic fermentation occurs in clean milk because this is the optimum temperature for *Streptococcus lactis*, which overgrows all other bacteria. A gassy fermentation may occur at this temperature if the milk has not been carefully handled. Milk held at 98.6° F. (37° C.) will become gassy if there are many coliform bacteria present, because they thrive at this temperature. If the milk has been produced in a clean manner, it will sour because of *S. lactis*. If the temperature of the milk is raised to about 107.6° F. (42° C.), *Lactobacillus bulgaricus* will sour the milk if present in considerable numbers, since it grows better than *S. lactis* at this higher temperature. At the still higher temperatures at which milk is pasteurized the thermophiles find their optimum growth conditions. For example, *L. thermophilus* grows rapidly at 150° F. (65.6° C.), and *Bacillus calidolactis* will cause coagulation of milk

at 159.8° F. (71° C.). Thus it is apparent that the temperature at which a food is held will determine within certain limits the type of organisms which will preserve or spoil it.

VI. THE PRESERVATIVE ACTION OF SALT

Salt is much more important in food preservation than is generally appreciated. It determines, within certain limits, the type of microorganisms which will grow in the food. Salt is added to many foods, such as butter, cheese, cucumbers, cabbage, cauliflower, onions, green tomatoes, eggs, and various types of meat and fish, as well as to bread, to control the microbial population which may be present in them. The amount of salt added to the food determines, first, what type of organisms shall grow, which in turn determines the type of fermentation which shall take place, and, second, whether or not certain undesirable organisms shall grow, since it is possible to add sufficient salt to inhibit the growth of many of the sporogenic anaerobes, like *Clostridium botulinum* and *C. sporogenes*, and the aerobic sporogenic bacteria, like *Bacillus mesentericus* and *B. subtilis*.

There are four theories commonly advanced to explain the preservative action of salt:

- (a) It exerts a poisonous action.
- (b) It makes moisture unavailable for the microorganisms.
- (c) It prevents bacterial growth by dehydrating the cells by plasmolysis.
- (d) It destroys bacterial protoplasm.

Each of these theories is briefly discussed in the following paragraphs.

1. Poisonous Action

Winslow and his students^{3,4} have shown that a wide variety of metallic ions (Na^+ , K^+ , Ca^{++} , Mg^{++} , Ba^{++} , Pb^{++} , and Hg^{++}) stimulate the growth of bacteria when present in sufficiently low concentration, and inhibit them in sufficiently high concentration. It is a quantitative rather than a qualitative relationship, and differs only in degree. A second factor is the $p\text{H}$ of the solution which, with a similar cation, is determined by the anion. Work⁵ with sodium chloride and acids shows the addition of acids (hydrochloric, acetic, citric, lactic, malic, and tartaric) reduces by 50% the amount of sodium chloride necessary for germicidal action.

2. Moisture Unavailable

There are two types of moisture; bound or unavailable, and free or available. See Volume I, page 273. It is the latter which largely determines the ability of organ-

³ F. W. Fabian and C. E. A. Winslow, *J. Bact.*, 18, 265 (1929).

⁴ C. E. A. Winslow and A. F. Dolloff, *J. Bact.*, 15, 67 (1928).

⁵ T. D. Nunheimer and F. W. Fabian, *Am. J. Pub. Health*, 30, 1040 (1940).

isms to grow and in which we are primarily interested. As previously stated, molds can grow on foods containing very small amounts of moisture, as low as 2 to 5%. Every bacteriologist knows how essential moisture is to bacteria and yeasts, for most of which it is a limiting factor. A few bacteria cannot grow in a medium containing 60% water, but most can grow in a medium containing 50% water and some even at 40%. Beyond this point, moisture becomes increasingly a limiting factor with yeasts and bacteria.

In foods to which salt has been added as a preservative, the question is how much of this water is available to the microorganisms. According to the physicochemical theory of solutions, when a salt such as sodium chloride is dissolved in water, it ionizes, collecting about each ion a group of water molecules, a process called ion hydration. The greater the concentration of the salt, the greater is the percentage of the total amount of water present as part of the hydrated ions. At 20° C., only 36 grams of sodium chloride can be dissolved in 100 grams of water, at which point saturation occurs. This gives approximately a 26.5% solution, in commercial practice called 100° salometer.^{5a}

Why is the saturation point reached at 100° salometer? The physical chemist will show, by calculation, that at this point the energy available for dissolving sodium chloride has been diminished to the extent that no more of the salt can be dissolved while in equilibrium with some of the solid component. This condition is called saturation. Whether there is any free water available for the growth of bacteria in a saturated solution is a problem the bacteriologist will have to answer by experimentation, since the physical chemist hesitates to give a definite answer.

3. Dehydration

If the theory of the dehydration of bacterial protoplasm is tenable, then the preserving action of salts in general should be proportional to their ability to dehydrate proteins; but such is not the case. Although it has been shown⁶ that magnesium sulfate has a greater dehydrating effect on proteins than sodium chloride, experiments⁷ with bacteria demonstrate that it is not so efficient in preventing bacterial growth as sodium chloride. Rockwell and Ebertz⁸ conclude from their work that at least five factors are involved in the preserving action of sodium chloride on bacteria, namely, dehydration, direct effect of the chloride ion, removal of oxygen, sensitization to carbon dioxide, and interference with the rapid action of proteolytic enzymes.

^{5a} Salometer refers to a commercial test based on a scale in which a saturated salt solution, that is, 26.5% at 20° C., is considered 100° salometer. Degrees salometer are measured by a calibrated specific gravity instrument (hydrometer) graduated with a 0 to 100° scale to be read directly in terms of degrees salometer. Thus 30° salometer means a solution which is 30% saturated with respect to salt. See D. Richardson, F. W. Fabian, and C. K. Wadsworth, "The Correct Use of the Salometer in Pickle Manufacture," *Fruit Products J.*, 19, 75 (1939) for a detailed discussion.

⁶ M. H. Fischer, *Oedema and Nephritis*. Wiley, New York, 1921.

⁷ M. McCutcheon and B. Lucke, *J. Gen. Physiol.*, 12, 129 (1928).

⁸ G. E. Rockwell and E. G. Ebertz, *J. Infectious Diseases*, 35, 573 (1924).

4. Osmotic Pressure

In discussing the possibility of cells being plasmolyzed by sodium chloride, one must consider the effect of salt on the permeability of the bacterial cells. One of the fundamental properties of living cells is their permeability to water. However, the degree of permeability may be surprisingly low, even temporarily nil. It varies with the physiological state of the cell, and also depends upon the chemical composition of the cell. Work⁹ done upon the permeability of unfertilized eggs of the sea urchin to water showed that sodium chloride and potassium chloride tended to increase the permeability of the cell to water, while calcium chloride and magnesium chloride tended to decrease it. Furthermore,⁹ the cells were more permeable to water, when the osmotic pressure of the medium was high than when it was low, explained by assuming that the water diffused through pores in a partially hydrated gel constituting the cell membrane. In a medium of high osmotic pressure, the gel is conceived to give up water and shrink, thereby widening the pores, so that water can diffuse through them more readily, while, in solutions of lower osmotic pressure, the gel may take up water and its pores become narrower.

There is no other group of plants, protophytes or metaphytes, or group of animals, protozoa or metazoa, that exhibits such physiological indifference to marked changes in osmotic pressure as do bacteria. Some idea of the resistance of certain bacteria to osmosis may be obtained from the literature, where growth is reported in nutrient solutions and on food containing from 2.5 to as high as 30% salt.

5. Selective Action on Microorganisms

Salt has a selective action on organisms. It permits the growth of certain lactic bacteria, some yeasts (such as *Mycoderma*, *Debaromyces*, and *Torula*), and many molds. Certain asporogenic and sporogenic aerobes and sporogenic anaerobes are inhibited by concentrations of salt that permit the growth of lactic bacteria, which produce sufficient acid to supplement the inhibiting action of salt. For example, the concentration of salt necessary to kill food poisoning staphylococci can be reduced 30% in the presence of one-half the inhibiting concentration of acid. By increasing the amount of acid, the amount of salt can be reduced 50% and still kill the staphylococci.⁵

Proteolytic and pectolytic bacteria are even more susceptible to acids than to salt. *Bacillus mesentericus fuscus*, *B. vulgatus*, and *B. mesentericus* grow readily in 9% and scantily in 11% salt, but are inhibited by 0.2% acetic and 0.3% lactic acids.¹⁰ *B. coagulans* and *B. calidolactis*, organisms causing sweet curdling in milk, are killed by approximately 0.1% lactic acid, whereas three times this amount are required to kill *Streptococcus lactis* and *S. liquefaciens*, organisms producing lactic acid in milk.¹¹

⁹ B. Lucke and M. McCutcheon, *J. Gen. Physiol.*, 10, 665 (1927).

¹⁰ F. W. Fabian and E. A. Johnson, Michigan Agr. Expt. Sta., *Tech. Bull.* 157 (1938).

¹¹ F. J. Erickson and F. W. Fabian, *Food Research*, 7, 68 (1942).

VII. PICKLES

1. Pickle Fermentation

There are many different kinds of pickles,¹² classifiable in three general groups, as follows: fermented pickles; unfermented fresh pasteurized pickles; and sweet, sour, and mixed pickles, and relish made from fermented pickles. Only the first group, which are fermented, will be discussed since they are the only ones in which micro-organisms play a part in preserving. It is necessary for the sake of clarity to subdivide them still further into three groups: overnight dill pickles; genuine dill pickles; and salt stock from which sweet, sour, and mixed pickles and relish are made.

Fresh cucumbers placed in a solution without any salt will become soft within 24 to 48 hours because of the action of bacteria which produce a pectin-dissolving enzyme.¹⁰ It is therefore necessary to add salt during the fermentation to suppress this type of bacteria. The addition of salt not only inhibits these bacteria but also permits the growth of lactic acid bacteria, which rapidly produce sufficient lactic acid to supplement the action of the salt. The amount of acid produced under normal conditions ranges from about 0.3 to 1.0% expressed as lactic acid, depending upon the type of fermented pickle.

(a) *Overnight Dill Pickles*

Overnight dill pickles are pickles produced by the natural fermentation of fresh cucumbers to which have been added a brine containing 5.3% salt (20° salometer brine), 10 to 15 pounds of cured dill weed, one pound of mixed spices, and one quart of 100-grain vinegar per barrel. One pound of garlic and/or onion may be added to make kosher-style pickles. This type of pickle should be placed immediately in cold storage at a temperature of at least 38° F. but not lower than 34° because the low salt concentration permits the growth of pectolytic bacteria, which will soften the pickles. At a temperature of 38°, a slow lactic fermentation will take place, and at the end of six months there will have been developed an acidity ranging from 0.3 to 0.6 % (3 to 6 grains) of acid. This type of pickle cannot be held for more than six months, preferably from three to four months, even at this low temperature without the possibility of serious losses occurring. This is due to the low salt and acid contents of the brine.

Some processors in making the overnight dill pickle permit it to undergo a primary fermentation prior to storage. A higher acidity is thus produced; but pickles so treated are more likely to spoil, since the amount of salt is not sufficient to prevent the growth of spoilage bacteria even in the presence of the increased acidity. Furthermore, one of the reasons for using cold storage is to prevent the usual curing process from taking place, so that the pickles will retain more of the flavor of green cucumbers, a flavor which many prefer but which is destroyed by a high salt concentration and fermentation.

¹² F. W. Fabian and R. G. Switzer, *Fruit Products J.*, 20, 136 (1941).

Since overnight dill pickles are so perishable, they are being replaced by fresh pasteurized dill pickles. These are made by placing fresh cucumbers in jars, covering them with the proper amount of brine containing salt, vinegar, dill, and four to six of the essential oils. Whole spices such as celery, mustard, and pepper seeds are sometimes added. The jars are sealed and pasteurized at 165° F. for 30 minutes. They retain the flavor of fresh cucumbers, have a low acid and salt content, and will keep several years. Thus, pickles packed in 1938 were still crisp and retained their original flavor after four years.

Overnight dill pickles contain, when finished, from 2 to 3% salt and from 0.3 to 0.6% acid, expressed as lactic.

(b) *Genuine Dill Pickles*

Genuine dill pickles are fermented pickles made at a higher salt concentration than the overnight dill type. They may be made in either barrels or large tanks holding 600 to 700 bushels of cucumbers. The barrel or tank is filled with freshly washed green cucumbers, 10 to 12 pounds of cured dill weed, one quart of whole spices, one quart of 100-grain vinegar, and a brine containing from 8.4 to 8.5% (32 to 36° salometer) salt. One pound of garlic buds may be added if kosher-style pickles are desired. Onions, horse-radish, grape leaves, and many other materials are sometimes added with the idea of improving the flavor; in many cases the addition of these materials hastens the spoilage of the product.

Genuine dill pickles undergo a primary lactic fermentation, in which the acidity increases very rapidly during the first week, and a secondary fermentation, in which the production of acid is more gradual. The finished pickles should contain from 3.5 to 4.5% salt and from 1.0 to 1.5% acid, expressed as lactic.

Temperature plays an important part in the genuine dill pickle fermentation. The ideal temperature for lactic fermentation is from 60 to 85° F. For pickle fermentation, however, lower temperatures, 60 to 70° F., are even better because within these temperature ranges less gas is produced. Kossowicz¹³ recommended 59° F. (15° C.) as the ideal temperature for pickle fermentation. High temperatures usually prevail during cucumber harvest. The cucumbers are placed in barrels, brined, and rolled into the sun for curing. A gassy fermentation ensues, creating a great pressure inside the barrel, frequently sufficient to burst the staves or to blow out the head or bung. This results in the loss of the pickles if not discovered, or in loss of flavor and acid if discovered and the pickles rebrined. For this and also economic reasons, a great many processors are making genuine dill pickles in large tanks, a step considered impossible less than a decade ago.

Because of the high temperatures prevailing in the South, it has never been possible to make genuine dill pickles without abnormal losses. Therefore processed dill pickles are made to supply the demand for this type. Processed dill pickles (imitation or

¹³ A. Kossowicz, *Z. landw. Versuchsw. Deut.-Oesterr.*, 11, 487 (1908); 12, 757 (1909); 14, 96 (1911); *Z. Gärungsphysiol.*, 2, 78 (1913).

summer dills) are made from salt stock by removing the excess salt and then adding a brine simulating genuine dill brine. This brine is made by heating dill weed and spices in a solution containing the desired amount of salt and acetic acid. The brine is then poured over the pickles. They remain in the brine for several days, until equilibrium has been established, at the end of which time they are packed in jars. The brine is reheated and poured over the pickles while it is still hot. The finished product generally contains from 3 to 4.25% salt and from 0.5 to 1.0% acid.

Genuine dill pickles under normal conditions are cured and ready to use within a period of about two months. In cold climates they cannot be left exposed to freezing temperatures because of their low salt content. They are sorted, placed in jars, and consumed within a period of a year or less. Pasteurization is not generally practiced, since it would injure the texture unless carefully controlled.

The bacteriology of genuine dill fermentation has not been definitely worked out because of the great variety of conditions under which they are packed and because of the varied microflora under different conditions.

Aderhold¹⁴ showed that fermentation began sooner under anaerobic than under aerobic conditions. At the end of three weeks, more acid was produced under anaerobic than under aerobic conditions. Kossowicz¹⁵ confirmed Aderhold's findings and conducted extensive experiments over a period of several years (1909, 1911, and 1913). Aderhold found that the pickles kept well in a 4 to 6% salt concentration, but spoilage was evident within the first two weeks with a salt concentration of 2% or less. Kossowicz used garlic, horse-radish root, oak leaves, and tannin in conjunction with high salt concentration to check the growth of undesirable bacteria and to speed up the growth of acid-forming bacteria. He found that pearl onions favored the development of lactic acid bacteria and that the addition of 1% tannin checked softening of the cucumbers.

Kossowicz¹⁵ studied the use of pure cultures of lactic acid bacteria. He advocated the use of starters from barrels of pickles which were undergoing a healthy fermentation. His work showed that the best results were obtained when the cultures were suspended in water to get an even distribution throughout the barrels. He recommended that the fermentation be carried out at 15° C. or lower, because that is the optimum temperature for growth of the lactic acid bacteria. Kossowicz used five milliliters of a vigorous culture to 15 to 20 kilograms of cucumbers, and believes that the acidity of the cucumbers should be 0.1% because, at that acidity, the lactic acid bacteria grow best.

Kossowicz¹⁵ also pointed out that the work of Gartz showed that 0.3% lactic acid completely suppressed the development of the coliform group, and that the work of Tillman showed that 0.2% lactic acid suppressed the mesentericus group. His own work indicated that members of the mesentericus group grew slowly in 0.2% lactic-acid-asparagine-sugar solution, and that no growth took place in this medium when 0.3% lactic acid was added.

¹⁴ R. Aderhold, *Centr. Bakt., Abt. II*, 5, 511 (1899).

Kornauth and Zanluchi¹⁵ carried out extensive experiments over a period of several years to determine the influence of various substances added to the pickles, and to study the influence of various bacteria on the cucumbers. They found *Escherichia coli* in all the pickles to which garlic had been added. They also found that *Bacterium gintheri*, *Bacillus lacticus*, and *E. coli* predominated after the first few days, and were doubtless responsible for the further increase in acidity.

Fabian and Wickerham,¹⁶ in their study of genuine dill pickles, found that there was a definite sequence of bacterial population. At the beginning of the fermentation, Gram-positive cocci predominated. These in turn were replaced by short rods, most of which were Gram-positive. Toward the end of the fermentation, long Gram-positive rods were in the majority. The authors concluded that, in the fermentation of dill pickles, there were three different phases caused by three different groups of bacteria. Weak acid-producing bacteria predominated throughout the fermentation. Strong acid-producing bacteria reached a maximum 8 to 10 days after the beginning of the fermentation, after which they gradually disappeared. The addition of 2 pounds of prepared mustard per barrel had no apparent influence on the fermentation; but the addition of sufficient acetic acid to produce an initial *pH* of 4.6 in the brine was desirable.

(c) Salt Stock Pickles

Cucumbers are harvested in large quantities over such a short period of time that it is impossible to prevent their spoilage except by brining. They cannot be canned, except as previously indicated in the case of fresh pasteurized pickles or by making them into bread-and-butter pickles. They cannot be frozen or dehydrated. So the only method left for preserving them is by brining. Over a period of years the art, but not the science, of brining has gradually evolved, until today the losses due to this method of preservation have been reduced to a minimum. There are still many problems connected with the brining of pickles that have not been satisfactorily solved.

There are two methods of brining in general use today. One is known as the low-salt, and the other as the high-salt, method. In the low-salt method of brining, fresh cucumbers are placed in an 8% (30° salometer) brine and 9 pounds of salt added for each 100 pounds of cucumbers placed in the tank. The tank when filled is fitted with a wooden cover which is fastened by timbers under pressure so that the cucumbers are completely immersed in the brine. The salometer test is raised two degrees each week until the brine test reaches 50° salometer, after which it is raised one degree each week until it reaches 60° salometer. This method is used in many places where normal temperatures prevail. Many salters start the tanks at even a lower brine test than 30° salometer.

Cucumbers salted by the high test method are started at 40° salometer, 9 pounds of salt being added for each 100 pounds of cucumbers. The salt concentration is raised two degrees each week until the brine tests 50° salometer, after which it is raised one

¹⁵ K. Kornauth and Fr. Zanluchi, *Z. landw. Versuchsw. Deut.-Oesterr.*, **16**, 1034 (1913).

¹⁶ F. W. Fabian and L. J. Wickerham, Michigan Agr. Expt. Sta., *Tech. Bull.* **146** (1935).

degree per week until the brine test reaches 60° salometer. This method is used in many places throughout the United States, especially in the South, except that the brine test is raised 5 to 7° per week instead of 2° because of the higher temperatures prevailing there.

Pickles preserved in 60° brine will keep for several years. However, it is a good practice to "feed" them salt gradually if they are to be kept for a longer time than from one season to the next. Also, in cold climates where the temperature reaches below zero, it is advisable to add more salt to lower the freezing point of the brine. For this reason, many salters feel safer when the brine test is 65 to 70° salometer. Pickles which are held longer than one year should test above 70° salometer to prevent loss from spoilage. About the only noticeable change in pickles held for 4 or 5 years in a proper brine solution is that they become darker in color and tend to lose their prime straw color.

Fermentation of Salt Stock.—In the curing of salt stock it is possible to have three distinct types of fermentation taking place at one time or another during the fermentation. The lactic fermentation is the main fermentation; the yeast and hydrogen fermentations may occur or may not, depending upon the prevailing conditions, such as microflora of the adhering soil, temperature, predominance of one group of organisms, amount of salt, and acidity of the brine. When they do occur, they are concurrent with the lactic fermentation. The three different fermentations are:

1. The true lactic fermentation, such as is produced by *Lactobacillus cucumeris*, in which the only by-product is lactic acid, or acid production as by *L. pentoaceticus*, which produces lactic and acetic acids in addition to alcohol, mannitol, and carbon dioxide.

2. A stormy fermentation, produced by yeasts, in which carbon dioxide is produced in large quantities.¹⁷ The concentration of the salt in the brine influences both the number of yeasts and the length of the yeast fermentation. At 20° salometer, the yeasts start to increase rapidly at the end of 3 days, reach a peak in about 9 days, and subside at the end of 25 days, while with 40° brine they start increasing rapidly at about the seventh day and reach a peak at the end of 2 weeks, after which they gradually subside.

3. Hydrogen fermentation,¹⁸ which has recently been recognized. It is due to the *Aerobacter* group of bacteria, and occurs in 20°, 40°, and 60° brines. The gas evolved consists of hydrogen and carbon dioxide in the ratio of 1:5 in cucumber juice. This ratio changes with the carbon source fermented. The most typical hydrogen fermentation occurs in the 60° brines. The 20° and 40° brines may or may not undergo typical hydrogen fermentation. In 40° and 60° brines, the fermentation is divided into two phases from the standpoint of gas evolution: The first is the *Aerobacter* fermentation, and the second, the yeast fermentation.

¹⁷ J. L. Etchells, *Food Research*, 6, 95 (1941).

¹⁸ J. L. Etchells, "A New Type of Gaseous Fermentation Occurring during the Salting of Pickles," *University Microfilms*, No. 282, 1-153. Ann Arbor, Michigan, 1941.

2. Role of Salt

Salt plays a dual role in pickle fermentation: It withdraws from the cucumbers water in which are contained the soluble nutrients such as protein, carbohydrates,

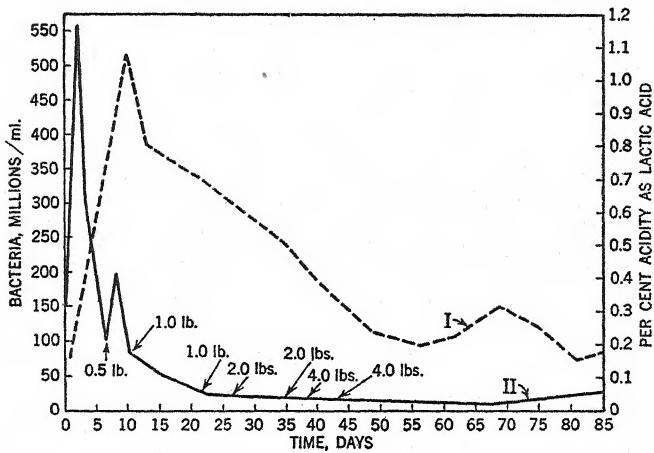


Fig. 61.—Influence of salt on cucumber fermentation in 30° salometer brine. Arrows indicate point at which salt was added. Curve I: acidity; curve II: bacteria.

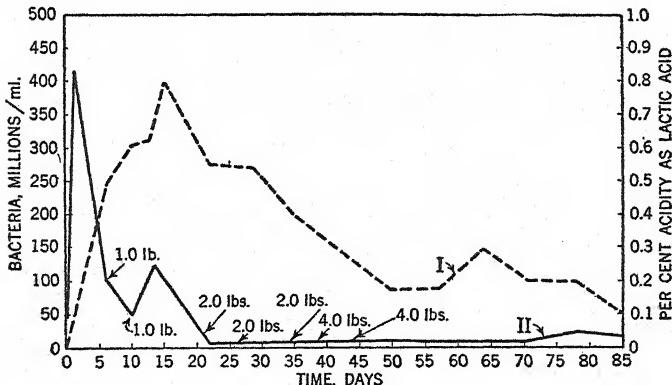


Fig. 62.—Influence of salt on cucumber fermentation in 40° salometer brine. Arrows indicate point at which salt was added. Curve I: acidity; curve II: bacteria.

minerals, and vitamins;¹⁹ and it suppresses the proteolytic and pectolytic bacteria, and permits certain of the lactic bacteria to grow.²⁰ The kind and numbers of bac-

¹⁹ L. J. Camillo, C. A. Hoppert, and F. W. Fabian, *Food Research*, 7, 339 (1942).

²⁰ F. W. Fabian, C. S. Bryan, and J. L. Etchells, Michigan Agr. Expt. Sta., *Tech. Bull.* 126 (1932).

teria surviving depend to a certain extent upon the salt concentration. This is well illustrated in Figs. 61 and 62. Here, the number of bacteria and per cent acidity are plotted against the time in days. During the first 24 hours, the acid bacteria reach a peak and then gradually decline until they number approximately one million at the end of $3\frac{1}{2}$ months. Practically the only difference between the 30° and 40° brines is their influence on the lactic acid bacteria, which show the greater reduction in numbers in the 40° brine. Proteolytic and pectolytic bacteria are not shown on this chart, but the data indicate that, in the 30° and 40° salometer brines, there are 110 and 45 millions, respectively, at the beginning. They reach a peak of 480 and 400 millions, respectively, within 24 hours, after which they gradually subside. They completely disappear at the end of 12 days in the 40° brine, and at the end of 15 days in the 30° brine. The acidity of the two brines follows in general the same trend as the acid bacteria. It reaches a higher amount (1.1%) sooner (within 10 days) in the 30° than in the 40° brine, where the maximum acid reached is 0.8% at the end of 15 days.

VIII. KRAUT

1. Fermentation of Kraut

There are many fundamental differences and some similarities between pickle and kraut fermentation. Cucumbers and cabbage differ in chemical composition. Cabbage has more protein, carbohydrate, and fat than cucumbers. This in turn influences the number and kind of bacteria, and also the amount and kind of products produced. For example, the amount of sugar in cabbage ranges from 2.9 to 4.2%,²¹ while in cucumbers it ranges from 1.2 to 2.2%.¹⁹ This difference in fermentable sugar contents makes possible the production of more acid in kraut than in pickles. The acidity of pickles ranges from 0.5 to 1.5%, with an average of around 1% for genuine dill and salt stock pickles. The acidity of freshly fermented kraut ranges from 1.5 to about 2.0%. The differences are also apparent in the salting procedures. It is necessary to add at least 8% salt to salt stock pickles to keep them from spoiling, while with kraut the ideal amount of salt to add is from 2.0 to 2.5%.²² An amount greater than 2.5% produces inferior kraut and is conducive to certain types of spoilage.²³ Pickles to which only 2.5% salt is added will spoil within a short time unless kept cold, as in the case of overnight dills. There is a similarity between pickles and kraut, since both undergo lactic fermentation during the curing process. Pickles are spiced, while kraut as made in America is not. In some European countries, kraut is flavored to some extent by the addition of apples, pears, dill pickles, and spices.

2. Manufacture of Kraut

The cabbage as it comes from the field is placed in well-aerated buildings, where it is allowed to remain for a day or two to wilt. This permits the cabbage to come to a

²¹ W. H. Peterson, E. B. Fred, and J. A. Viljoen, *Canner*, 61 (4) 19 (1925).

²² C. S. Pederson and C. D. Kelly, N. Y. State Agr. Expt. Sta., *Bull.* 613 (1932).

²³ C. S. Pederson, N. Y. State Agr. Expt. Sta., *Bull.* 595 (1931).

more uniform temperature, and to be cut with the least amount of breaking of the shreds. The cabbage then passes by conveyors to workers who trim the outer green leaves and cut out any bad spots, after which it is cored by means of an augerlike drill which allows the finely cut core to remain in the cabbage. It then passes directly to the cutting machine where large power-driven rotary knives slice it. From there the shredded cabbage is conveyed to the curing vats for salting. The salting may be done in the vat or in the carts which are sometimes used to transport the shredded cabbage to the curing vats. Salt is added in the ratio of 2 to 2.5 pounds per 100 pounds of cabbage. It should be evenly distributed throughout the cabbage to prevent certain types of spoilage which will be discussed later. It is preferable to allow the salt to act on the shredded cabbage for a few minutes before packing it in the tank. This will make it more pliable and require less tamping in the vats. After the vats have been filled, they should be weighted down sufficiently so that the brine completely covers the cabbage at all times. Otherwise the top layer of kraut will have to be discarded when the vat is emptied because it may be soft or discolored.

The temperature of the cabbage within the vat should be kept between 60 and 75° F. during the fermentation. Temperatures below 60° result in a slow, and often incomplete, fermentation of the cabbage until the following spring. Too high temperatures, on the other hand, result in a very rapid fermentation and sometimes in soft kraut. Evidently a rather wide range of temperature is satisfactory, since different investigators recommend different ranges and optimum temperatures for kraut fermentation.²⁴⁻²⁷ The temperatures considered optimum for kraut making do not correspond with the optimum temperatures of growth, *viz.*, 77 and 86°, for the bacteria considered necessary for the fermentation of kraut.²⁷

Kraut, under the definition of the Federal Food and Drugs Act, is the clean, sound product of characteristic flavor, obtained by full fermentation, chiefly lactic, of properly prepared and shredded cabbage in the presence of not less than 2% nor more than 3% salt. It contains, upon the completion of fermentation, not less than 1.5% of acid expressed as lactic acid. Sauerkraut which has been rebrined in the process of canning should contain not less than 1% acid.

Pederson and Kelly analyzed 102 cans of kraut from 71 different packers throughout the United States and found that kraut containing between 2.0 and 2.5% salt showed the best texture. Salt also influenced other qualities, but the relationships were so complicated that the authors could establish no definite correlations. The majority of krauts with a high quality rating showed a normal chemical analysis of volatile acid, total acid, alcohol, and salt. Pederson,²⁸ 8 years later, analyzed 332 samples of canned kraut and found that the better quality krauts showed more constant amounts of

²⁴ H. B. Parmele, E. B. Fred, W. H. Peterson, J. E. McCorkie, and W. E. Vaughn, *J. Agr. Research*, 35, 1021 (1927).

²⁵ E. A. Marten, W. H. Peterson, E. B. Fred, and W. E. Vaughn, *J. Agr. Research*, 39, 285 (1929).

²⁶ C. S. Pederson, N. Y. State Agr. Expt. Sta., *Bull.* 614 (1932).

²⁷ C. S. Pederson, N. Y. State Agr. Expt. Sta., *Tech. Bull.* 168 (1930).

²⁸ C. S. Pederson, N. Y. State Agr. Expt. Sta., *Bull.* 693 (1940).

acids, salt, and alcohol than did the poorer quality krauts and, in general, contained more vitamin C. These data are shown in Table 31.

TABLE 31

AVERAGE CHEMICAL COMPOSITION AND VARIATION FROM THE AVERAGE OF SAMPLES OF CANNED KRAUT

Analysis	Total acid range, %	Volatile acid range, %	Ratio range	Alcohol range, %	Salt range, %	Ascorbic acid, mg. per gram	Samples not within range, total %
Ideal	1.1-1.5	0.15-0.30	0.20-0.30	0.15-0.25	1.7-2.4	0.15 and up	..
Permissible	1.0-up	0.10-0.30	0.15-0.35	0.10-0.35	1.5-2.5	0.10 and up	..

Number of Samples above or below Permissible Analysis

Kraut	Above	Above	Below	Above	Above	Above	Below		
Good, 190	19	4	..	6	7	2	9	...	20
Fair, 79	14	3	..	7	7	7	14	...	46
Poor, 63	13	3	1	11	9	11	12	...	67

3. The Bacteriology of Sauerkraut

A bacteriological analysis of the freshly packed cabbage in the vat shows a number of Gram-negative, low-acid or nonacid producing organisms which happened to be on the cabbage when cut. Presumably they are soil and various soft rot bacteria. These organisms soon disappear because of environmental factors such as salt concentration and lack of oxygen; and a second group appears that can flourish under the prevailing conditions. The second group consists of gas-producing cocci, the predominant species of which is *Leuconostoc mesenteroides*, which produces lactic and acetic acids, alcohol, and carbon dioxide from glucose, and mannitol from fructose. These bacteria initiate the kraut fermentation and reach a peak between the first and second days, after which they gradually die off and are supplanted by a third group. During the active period of the second group, the acidity of the brine reaches from 0.7 to 0.9% and, at lower temperatures, 0.8 to 1.0%. Their optimum temperature for growth is 77° F. The pleasant flavors of kraut may also be attributed to the action of this group, which will also grow at lower temperatures than the lactobacilli which follow them. It is for this reason that kraut kept at too low temperatures has a low acidity, since the gas producing cocci are not capable of producing more than 1.0% acid from cabbage.

Under the proper conditions of temperature a third group, the lactobacilli, start to multiply rapidly at the end of the second day and reach a maximum between the third and fifth days of the fermentation, after which they gradually disappear and a fourth group takes over. The principal member of this third group is *L. cucumberis* which is a non-gas producing, Gram-positive, short rod capable of increasing the acidity to as

high as 1.5% under ideal conditions. It has an optimum temperature of 86° F., and ferments the sugars present in kraut brine chiefly to lactic acid without production of gas. This group is microaerophilic.

The fermentation of the kraut is completed by a fourth group of bacteria, again lactobacilli, the principal member of which is *L. pentoaceticus*. This group starts in where *L. cucumeris* leaves off, and reaches a peak at the end of 7 days. It is capable of producing as high as 2.4% acid. The principal products of fermentation by *L. pentoaceticus* are lactic and acetic acids, alcohol, and carbon dioxide from glucose, and mannitol from fructose. They are the longer Gram-positive rods found in kraut and vary in length from 1 to 5 μ or longer. They are microaerophilic and have an optimum temperature of 86° F.

Theoretically, it is possible to make shredded cabbage into kraut within a period of 7 days under ideal conditions. Practically, however, it requires 3 to 4 weeks or longer, depending upon the temperature conditions. As soon as the kraut has reached an acidity of 1.5%, it can be canned. Kraut is not kept for several years, as is often done with salt stock pickles. The first kraut made in the fall is usually canned several weeks after the fermentation is completed. All the vats are generally canned by midsummer or earlier. Often, a vat is filled with kraut two or more times in a season.

Starters.—The use of starters for making kraut is preferred by some makers, while others claim that they cannot be used to advantage. Peterson, Fred, and Viljoen²⁹ claim that with 16 lots of experimental kraut the addition of selected cultures of bacteria to the cabbage at the time of filling the vats gave a superior quality kraut with a better color and texture. Inoculation of shredded cabbage with *Streptococcus lactis* originally obtained from milk altered the normal flavor of kraut and gave an improved product. The effect of the inoculation was to change the fermented products. The inoculated kraut contained more lactic acid, and less acetic acid and ethyl alcohol, than the noninoculated kraut.³⁰ Pederson³¹ found that inoculation of the shredded cabbage with *S. lactis* apparently had a detrimental effect. The high lactic acid and the low acetic acid and alcohol contents of the finished kraut made it taste like acid cabbage. Cabbage inoculated with mixed cultures, *S. lactis*, *Leuconostoc mesenteroides*, and *Lactobacillus pentoaceticus* fermented in two days less time with practically the same results as with the noninoculated cabbage. Later work³² showed that cabbage inoculated with *S. lactis* showed a slight improvement in quality, but the main changes in flora, acid development, and chemical analysis of the final product were about the same as those of normal kraut. Cabbage inoculated with *L. mesenteroides* produced kraut that was normal in flavor but low in acid, while that inoculated with *Lactobacillus cucumeris* and *L. plantarum* produced kraut that was poorer in flavor and odor and apparently more susceptible to spoilage by yeasts.

²⁹ W. H. Peterson, E. B. Fred, and J. A. Viljoen, *Canning Age*, 6, 777 (Sept., 1925).

³⁰ O. R. Brunkow, W. H. Peterson, and E. B. Fred, *J. Agr. Research*, 30, 955 (1925).

³¹ C. S. Pederson, N. Y. State Agr. Expt. Sta., *Tech. Bull.* 168 (1930).

³² C. S. Pederson, N. Y. State Agr. Expt. Sta., *Tech. Bull.* 169 (1930).

Kraut produced by inoculating the shredded cabbage with *L. pentoaceticus* was poorer in quality and had a higher ratio of volatile to nonvolatile acids.

The work was continued³³ with an attempt to improve the normal fermentation of sauerkraut by using starters composed of pure cultures, mixtures of pure cultures, and the juice of tanks of kraut undergoing normal fermentation. The best results were secured with cultures of *S. lactis* and *L. mesenteroides*. A definitely detrimental effect was attributed to starters consisting primarily of *L. pentoaceticus* and *L. cucumeris*. From the extensive work of Pederson, it would appear that there is no advantage in using starters in kraut fermentation and that starters consisting of certain groups of bacteria are detrimental. The best way to make good kraut is to control such factors as salt, temperature, kind and quality of cabbage, cleanliness of the vats, and general plant sanitation. If these factors are controlled satisfactorily, shredded cabbage will undergo a normal fermentation in which there will be a natural sequence of bacterial populations, each of which will contribute its share to the flavor and chemical composition of the finished kraut.

4. Spoilage of Kraut

(a) Pink Kraut

Pink kraut is due to the growth of pink yeasts on the surface of the kraut. It is more commonly found when the salt content is too high,³⁴ when the kraut has not been properly weighted to exclude air, or where there are air and salt pockets.³⁵ Pink kraut may develop in kraut inoculated with a pure culture of lactic acid bacteria or in kraut to which a small amount of lactic acid has been added prior to fermentation.^{34, 36, 37} Fermentation at too high a temperature,³⁸ the addition of old kraut juice as a starter to freshly shredded cabbage, and improperly cleaned vats are all conditions conducive to the development of pink kraut.³⁴ There is also the possibility that a low nitrogen content in cabbage favors the development of pink kraut.^{39, 40} Certain iron salts and xylose favorably affect the production of pink kraut and oxygen appears to be a necessity.⁴¹ A low acidity with an increased alcoholic content is especially favorable for the growth of certain types of pink yeasts. Briefly, any factor that tends to inhibit or retard the normal sequence of bacterial growth in kraut fermentation favors the growth of pink yeasts and therefore the development of pink kraut.

³³ C. S. Pederson, N. Y. State Agr. Expt. Sta., *Tech. Bull.* 216 (1933).

³⁴ C. S. Pederson and C. D. Kelly, *Food Research*, 3, 583 (1938).

³⁵ C. S. Pederson, N. Y. State Agr. Expt. Sta., *Bull.* 595 (1931).

³⁶ O. R. Brunkow, W. H. Peterson, and E. B. Fred, *J. Am. Chem. Soc.*, 43, 2244 (1921).

³⁷ W. Hennenberg, *Deut. Essigind.*, 20, 133 (1916).

³⁸ E. A. Marten, W. H. Peterson, E. B. Fred, and W. E. Vaughn, *J. Agr. Research*, 39, 285 (1929).

³⁹ W. H. Peterson, H. B. Parmele, and E. B. Fred, *Soil Sci.*, 24, 299 (1927).

⁴⁰ C. Wadeigh, *Kraut Cabbage Research*. Presented at Natl. Kraut Packers Assoc., July, 1932.

⁴¹ E. B. Fred and W. H. Peterson, *Centr. Bakf.*, Abt. II, 58, 199 (1923).

(b) *Soft Kraut*

Soft kraut is usually associated with air pockets, faulty salting, high temperatures, or faulty fermentation. Bacteria causing the desirable fermentation of kraut are microaerophilic, that is, they require only a small amount of air. If the cabbage is not packed tightly to exclude the air, undesirable bacteria grow and cause softening of the cabbage. A low salt content, below 1%, likewise permits the growth of undesirable bacteria. High temperatures at the start of fermentation do not permit the proper sequence of bacteria to function normally. The rod forms grow first and have a greater ability to break down the structure of the cabbage than do the cocci.

(c) *Slimy or Ropy Kraut*

Slimy or ropy kraut is due to the growth of *Lactobacillus cucumeris*. At high temperatures, the organism becomes encapsulated and slimy, thereby producing a slimy or ropy kraut which is harmless, but objectionable because the kraut is not salable. A similar condition is found in sugar factories, dairies, pickle tanks, and many places where the proper conditions prevail for the growth of certain types of ropy bacteria.

(d) *Rotted Kraut*

Rotted kraut is caused by the presence of certain types of bacteria, yeasts, and molds, and in some cases by fruit flies. In the instances in which the kraut is black and soft or completely broken down, a very disagreeable odor is produced which may diffuse for several feet into the vat, causing an off-flavor in what would otherwise be edible kraut. Surface rotting of kraut can be overcome to a considerable extent by spreading a heavy muslin cloth over the surface of the kraut when packed and pushing it well down the sides of the vat. The vat cover is placed over this arrangement and weighted so that the juice does not flow out over the cloth. The cloth will both keep fruit flies from the kraut and keep the kraut moist, thereby inhibiting the growth of the organisms causing the trouble.

(e) *Off-Flavors*

Off-flavors in kraut may be the result of the improper sequence of bacterial growth. If the gas producing lactobacilli fermentation precedes the gas producing cocci fermentation, a sharp or biting kraut may result. Sometimes the non-gas producing lactobacilli predominate, and produce a kraut with a raw or unfermented bitter cabbage flavor which is accentuated by the destruction of the sugar in the kraut. Off-flavors attributed to decomposed kraut have already been discussed.

IX. VEGETABLES

1. Green Tomatoes

Tomatoes, although botanically a fruit, may be considered in this section by virtue of their acceptance as a vegetable.

Green tomatoes can be preserved in a manner similar to that used for pickles by placing them in a 30° or 40° salometer brine and allowing them to ferment.⁴² Because of their low sugar content, which ranges from 0.25 to 1.57%, it is sometimes advisable to add either dextrose or sucrose to increase the final acidity. Most processors pack the tomatoes late in the fall so that, because of the cold weather, they do not undergo a very active fermentation. The salt content must be increased two degrees salometer per week to at least 60° salometer to prevent freezing. Green tomatoes are used to make green tomato pickles or to make relish in combination with pickles.

Green tomatoes preserved in a 30° salometer brine without the addition of dextrose develop a total titratable acidity of only 0.15 at the end of nine days. The fermentation is a typical but mild lactic fermentation with many peptonizing bacteria present. When 2.5% dextrose is added to the brine, 0.66% acid is developed in about seven weeks. Under these conditions, the fermentation is more active and no peptonizing bacteria appear on the plates. Fermentation improves the quality of green tomatoes but the acidity produced is so small that it cannot be depended upon to keep them. They should be preserved in at least 60° salometer brine if they are to be held for any length of time.

2. Onions and Cauliflower

Onions and cauliflower are best preserved in salt without any fermentation. For this reason, the final salt concentration must be at least 80° salometer. Onions which are allowed to ferment become soft and the various layers loosened. Even in high brines, the outer layer is soft and must be discarded before using. Cauliflower likewise is injured by fermentation. Unless it is properly salted, it softens during processing and finishing becomes mushy.

3. Peas and Green Lima Beans

Peas and green Lima beans can be preserved by brining in at least 70°, but preferably 80° salometer brine. Extensive experiments⁴³ carried out in the summer of 1942 on a number of vegetables showed that peas and green Lima beans could not be successfully preserved if they were allowed to ferment. Salt concentrations ranging from 30 to 90° salometer at 10° intervals were tried. It was found that, if these two vegetables were allowed to ferment, their flavor was spoiled. At salt concentrations lower than 70° salometer, fermentation took place in proportion to the amount of salt present. The acidity which developed gave the peas and green Lima beans an undesirable sour flavor which did not disappear upon processing.

4. Green String Beans, Corn, and Okra

Green string beans, corn, and okra have all been successfully preserved in low salt brines which permitted lactic fermentation. Experiments have been run at 40, 60,

⁴² F. W. Fabian and F. J. Erickson, *Fruit Products J.*, 19, 363, 377, 379 (1940).

⁴³ F. W. Fabian and H. B. Blum, *Fruit Products J.*, 22, 228 (1943).

and 80° salometer. The salt concentration on the vegetables placed in the 40° salometer brines was raised two degrees salometer per week until the brine tested 60° salometer. The salt concentration on the 60° and 80° salometer brines remained constant. Green string beans underwent a slow fermentation in the 40° salometer brine until the brine reached an acidity of 1.0%. The higher salt brines developed only 0.5% acid, their color and texture being good and flavor fair.

Whole-kernel corn treated in the same manner as the green string beans developed an acidity of 1.0% in the 40° salometer brine and about 0.2% acid in the 60 and 80° salometer brines. The color and texture were good and the flavor fair.

Okra developed an acidity of 0.4% in the 40° salometer brine and 0.2% in the 60 and 80° salometer brines. The color changed to a yellowish green in the low brine, but was retained in the two high brines. The texture was good and the flavor fair.

This series of experiments demonstrates that it is possible to preserve vegetables such as peas and green Lima beans only in high salt brines, 70° salometer or above, in which practically no bacterial growth takes place. The high protein content of these two vegetables as compared with green string beans, corn, and okra doubtless accounts for this fact. Corn and okra, on the other hand, could be fermented without injury to their flavor; they have a lower protein content and sufficient sugars to permit the production by bacteria of enough acid to be of some preserving value.

X. DAIRY PRODUCTS

1. Butter

There are several kinds of butter, depending upon the manner in which they are made: sweet cream butter made from sweet cream without the use of a starter, and sour cream butter made from naturally soured cream or from pasteurized cream to which a starter has been added. Salt may or may not be added to butter made from any of these different types of cream. So there are, also, unsalted and salted butters.

The average chemical composition of American creamery butter is 82.41% fat, 13.9% water, 1.18% curd, and 2.51% salt.⁴⁴ The low moisture content would preclude the possibility of much microbial activity, except for molds, were it not for its physical structure. Butter is an emulsion of water in fat and in the interstices of the fat globules there are sufficient moisture and soluble food to support bacterial growth. The number of water droplets range from 10 to 18 billion per gram. If the salt were evenly distributed throughout, there would be 2.5% salt in the water droplets. Under actual conditions it is highly probable that the droplets in some of the interstices have no salt while in others the concentration is much greater.

Salt plays a very important part in butter preservation. Hammer⁴⁵ says that, from the standpoint of the microbiology of butter, there is a striking difference between the salted and unsalted products. Unsalted butter presents more of a problem than salted butter since salt definitely inhibits the growth of some species of organisms and may

⁴⁴ S. C. Thompson, R. H. Shaw, and R. P. Norton, U. S. Dept. Agr., *Bull. 149* (1912).

⁴⁵ B. W. Hammer, *Dairy Bacteriology*. Wiley, New York, 1938.

even kill others. However, salt is not a panacea for butter troubles because certain undesirable chemical changes may occur much more readily in salted than in unsalted butter.

Washburn and Dahlberg⁴⁶ found that, in unsalted butter, the bacteria increased more rapidly at 58° F. (14.4° C.) than in salted butter; but at -15° F. (-21.6° C.) they decreased more rapidly. Hammer and Hussong⁴⁷ likewise found that unsalted butter increased in bacterial content at 69.8° F. (21° C.) or 44.6° F. (7° C.), while salted butter from the same churning tended to decrease at the same temperatures. Macy, Coulter, and Combs⁴⁸ found that salt checked yeasts and bacteria but had a less inhibitive effect on molds. Sommer and Smit⁴⁹ found that salt was one of the factors contributing to the fishy flavor in butter.

There is a variation in the amount of salt added to butter. Canada requires that not over 2% be added to butter unless requested by the purchaser. It is now considered that a high salt content may, and frequently does, accelerate deterioration in butter, and that it is more detrimental in high-acid than in low-acid butter. From 2 to 2.5% salt is recommended in sweet cream or in first-grade cream butter, and less than 2% for second-grade cream butter.

Bacteria play another important role in butter. The desirable flavor of butter comes from two sources, the milk components, especially milk fat, and the products formed by certain bacteria. In the butter industry, bacterial cultures or starters are widely used to impart a high flavor to the butter which is desired in many markets. These starters generally consist of a mixture of bacteria, *Streptococcus lactis*, *S. citrovorus*, and *S. paracitrovorus*. *S. lactis* ferments lactose, producing lactic acid, while the latter two ferment citric acid to produce acetyl methyl carbinol, which in turn is oxidized to diacetyl. It is the diacetyl which imparts a pleasant aroma to butter.

It has been shown that the numbers of various types of organisms in butter are no general indication of either the original quality of the product or its keeping qualities because of the influence of so many other factors. In general, butters with low yeast, mold, and bacterial counts keep better than those with high counts; but on individual butters the counts do not serve as a reliable index.

2. Cheese

There are many different kinds of cheese. Practically every country has its own particular cheese or cheeses.⁵⁰ Cheese may be classified under two general headings: those in which the curdling is due primarily to the action of rennet; and those in which the curdling is due primarily to acid developed by bacteria.

The rennet curd cheese may be subdivided into hard cheeses, semisoft cheeses, and

⁴⁶ R. M. Washburn and A. C. Dahlberg, *J. Dairy Sci.*, 1, 114 (1917).

⁴⁷ B. W. Hammer and R. V. Hussong, Iowa State Agr. Expt. Sta., *Research Bull.* 134 (1930).

⁴⁸ H. Macy, S. T. Coulter, and W. B. Combs, Minnesota Agr. Expt. Sta., *Tech. Bull.* 82 (1932).

⁴⁹ H. H. Sommer and B. J. Smit, Wisconsin Agr. Expt. Sta., *Tech. Bull.* 57 (1923).

⁵⁰ R. S. Breed, C. D. Kelly, J. C. Marquardt, and J. A. Tomasi, N. Y. State Agr. Expt. Sta., *Circ.* 187 (1939).

soft cheeses, depending upon their moisture content. There is no sharp dividing line between these three types because there is a gradation from one type to the other. Typical hard rennet cheese ripens quite uniformly throughout the mass, and for this reason may be made in large sizes. It has good keeping qualities, since it is not subjected to the rapid action of objectionable microorganisms. Microorganisms, however, play an important part in the ripening of soft rennet cheeses. They develop at the surface and their products of growth diffuse throughout the cheese, effecting the characteristic changes which occur during the ripening process. For this reason the cheese is limited in size. Because the opportunity for growth of microorganisms, even after the cheese has ripened, results in overripening with its objectionable features, the keeping qualities of soft rennet cheeses are limited.

The flavor of the acid curd cheeses develops during manufacture, so they require no definite ripening period. There may be an increase in the pleasing flavor for some time after the cheese is made, but the continued growth of the microorganisms finally results in abnormal flavors.

The ripening of cheese is due to the action of microorganisms and of enzymes normal to the milk or added in the coagulating enzyme. More than one species of microorganism is usually concerned in the ripening process. In some cases, there may be a sequence of microflora, depending upon the products formed. One of the principal functions of organisms is the production of acid. Hammer,⁴⁵ in discussing acid development, lists five important functions it has in cheese ripening: It favors the curdling of the milk with rennet, the expulsion of whey, the fusing of the curd particles, and the action of the pepsin present in the rennet extract, and it has a protective action against putrefaction.

(a) Cheddar Cheese

Babcock and coworkers⁵¹ early noted that, when cheese curd was washed free of acid and sugar, it decomposed rather quickly as a result of the action of putrefactive organisms. Kelly⁵² concluded that acid production was the important function of bacteria in Cheddar cheese, and that either *Streptococcus lactis* or *S. cremoris* was satisfactory for this purpose. Lactobacilli such as *L. casei* develop rather late in the ripening period of cheese, and bring about desirable changes in connection with the breaking down of protein. Their growth results in an increase in the soluble nitrogen.

(b) Swiss or Emmenthaler Cheese

Different groups of microorganisms are found in different cheeses because of the method used in making the cheese. The curd of Swiss or Emmenthaler cheese is cooked at a relative high temperature, 126 to 140° F. (52.2. to 60° C.), which kills many of the less resistant bacteria, so that a somewhat different bacterial flora grow and consequently produce a different flavored cheese. *Streptococcus thermophilus*, a

⁵¹ S. M. Babcock, H. R. Russell, A. Vivian, and E. G. Hastings, Wisconsin Agr. Expt. Sta., 18th Ann. Rept., 1901, p. 162.

⁵² C. D. Kelly, N. Y. State Agr. Expt. Sta., Tech. Bull. 201 (1932).

heat-resistant organism, takes the place of *S. lactis*, and produces sufficient acid at the beginning to meet the requirements of this type of cheese. *Lactobacillus casei* or *L. bulgaricus* likewise plays an important part in increasing the acidity, thereby limiting abnormal fermentations and aiding in control of the ripening. Finally, propionic bacteria (*Propionibacterium*) are essential to produce the characteristic holes, and aid in the development of the typical flavor found in this cheese.

(c) *Blue-Veined Cheese*

Blue-veined cheeses like Roquefort, Gorgonzola, and Stilton are semihard rennet varieties in which bacteria and molds play an important part in the manufacture. *Streptococcus lactis* is considered necessary in making this type of cheese in order to produce sufficient lactic acid to control putrefactive bacteria. Likewise, *Penicillium roquefortii* is necessary to break down the proteins and fats into simpler compounds from which the characteristic flavor is derived in the ripened cheese.

(d) *Camembert Cheese*

Camembert cheese is made with cultures of *Streptococcus lactis*, to control undesirable bacteria by acid production, and cultures of *Penicillium camemberti*, to assist in the ripening and to produce the characteristic flavor. The addition of 2.5 to 3.0% salt also assists in keeping down other undesirable organisms, such as *Oospora lactis*.

(e) *Cottage Cheese*

Cottage cheese belongs to the group of acid curd cheeses. It may be produced by allowing milk to sour spontaneously or by pasteurizing the milk and adding a starter. The strain of *Streptococcus lactis* used produces sufficient acid to curdle the milk and impart the characteristic lactic flavor. A small amount of rennet may be added to form a softer curd. A more desirable flavor may be produced upon standing if the proper bacteria are present. Because of the high moisture content, cottage cheese has poor keeping qualities.

Various other organisms in addition to those just mentioned are found in cheese more or less frequently, some of which have a desirable and others an undesirable influence on the ripening process. Among the organisms found to have a desirable effect may be mentioned *Streptococcus kefir*, *S. citrovorus*, *S. paracitrovorus*, and *S. liquefaciens*, which improve the flavor. Bacteria such as *Alcaligenes viscosus*, *Achromobacter lipolyticum*, and *Pseudomonas fluorescens* have little effect on the flavor of cheese while *Pseudomonas fragi* decreases the flavor.

XI. MEAT

Microorganisms are not so useful in the meat industry as in the vegetable, fruit, or dairy industry. This is doubtless due to the high protein content of meat in relation to its carbohydrate content, to the pH, the oxygen relationships, and the method of

handling. In fact, organisms in most cases do more harm than good to meat and meat products.

1. Spoilage

(a) Green Discoloration

Green discoloration in meat may be due to two causes: undercure; and the growth of oxidizing and hydrogen sulfide producing microbes upon cured and fresh meats. Undercured meat results from the failure of the nitrite and other curing ingredients to penetrate into the meat during the curing process. This in turn results in the failure of the hemoglobin or myoglobin to become fixed in the tissues so that the more heat-stable nitroso derivatives (such as nitrosohemoglobin and nitrosohemochromogen) of these chromogenic compounds are not formed. When such undercured meat is heated, it becomes discolored. Bacteria like *Streptococcus viridans* or other oxidizing types are capable of changing the pink ferrous nitroso derivatives of hemoglobin to an emerald-green and a gray-green color. Bacteria producing hydrogen sulfide are also capable of causing the green discoloration in meat. These color changes, while objectionable, are in no way harmful or poisonous.⁵³

(b) Ham Souring

Ham souring really is not souring, as this term is commonly used, but is putrefaction. According to Jensen and Hess,⁵⁴ there are six or more sufficiently different types of ham souring to warrant the following designations: shank, body, aitchbone, stifle-joint, body-bone, butt, and puffers, a gaseous condition in ham which is no longer encountered. See Volume I, page 461. They studied nearly one-half million hams and shoulders trying to find the cause of the trouble and measures to correct it. Starting with the microflora of the hog's skin, they followed the bacteriology of the butchering, processing, and curing of the meat throughout these various processes, and concluded that bacteria like *Achromobacter*, *Bacillus*, *Pseudomonas*, the *Proteus* group, *Serratia*, *Streptobacillus*, *Micrococcus*, and *Clostridium*, and a miscellaneous group which can grow at 32 to 38° F. (0 to 3.3° C.) in marrows and which are salt-tolerant, can cause any of the different kinds of sours.

2. Ripening and Tenderizing

Ripening and tenderizing of beef is accomplished by aging it in coolers under controlled humidity and temperature conditions. Some workers⁵⁵ believe that meat tenderizing during storage is due largely to autolytic enzyme action. Gibbons and Reed⁵⁶ found that the degree of autolysis prior to the introduction of bacteria, while

⁵³ L. B. Jensen, *Microbiology of Meats*. Garrard, Champaign, 1942.

⁵⁴ L. B. Jensen and W. R. Hess, *Food Research*, 6, 273 (1941).

⁵⁵ R. Hoagland, C. N. McBride, and W. C. Powiek, U. S. Dept. Agr., *Bull. 433* (1917).

⁵⁶ N. E. Gibbons and G. R. Reed, *J. Bact.*, 19, 73 (1930).

not affecting the growth rate, did make a marked difference in the subsequent chemical changes. Jensen⁵³ states that, during the holding period, molds of several genera, usually species of *Mucor*, *Rhizopus*, and *Thamnidium*, and bacterial species of *Achromobacter* and *Pseudomonas*, appear on the cut surfaces of the beef. Hundreds of examinations have revealed this flora, so that their presence serves as an index of proper cooler conditions. Comprehensive eating tests by expert meat judges unanimously favored meat so ripened to meat ripened and tenderized at the same time under similar conditions except that the characteristic microflora was prevented from developing by spraying with chemical preservatives.

3. Flavor

Thuringer and Essex sausage and Lebanon Bologna are types of meat products in which bacteria play a leading role in the manufacture. Thuringer and Essex types of sausage have a tangy acid flavor which has been shown to be due to many species of lactobacilli and occasionally to *Leuconostoc*.⁵⁷ These sausages are made from chopped beef mixed with sodium nitrate, salt, sugar, white pepper, and whole black pepper. Chance inoculation with bacteria which produce sufficient lactic acid is responsible for the tangy flavor. Jensen and Paddock⁵⁷ found that starters could be made from several species (such as *Lactobacillus casei*, *L. plantarum*, *L. cucumberis*, *L. pentosus*, *L. arabinosus*, *L. leichmannii*, *L. acidophil-aerogenes* A. B., and H., *L. pentoaceticus*, *L. gayonii* and *L. mannitopoeus*) and used to advantage. Some of the above species, as *L. cucumberis*, often produced too much acid for sausage. Certain species, as *L. pentoaceticus*, were better adapted for Lebanon Bologna. Gas producers, like *L. lycopersici*, are not as desirable as the straight acid producers. Pure culture starters made from desirable bacteria added in about 1% proportions to the sausage or Bologna at the last mixing operation just before stuffing eliminated many steps or shortened others, besides producing a uniform product.

XII. SALT RISING BREAD AND SAUERTEIG

Breads may be classified as leavened and unleavened. It is possible to leaven bread by either chemical or biological agents. The real purpose of a leavening agent is to make the bread light. It has been found that the simplest and easiest way to effect this is by means of a gas, the two most easily generated, nontoxic gases being carbon dioxide and hydrogen. Of the two, carbon dioxide is preferable because it is the heavier and escapes from the bread less readily. All the chemical methods, such as those employing tartrate-bicarbonate, phosphate-bicarbonate, or alum-bicarbonate mixtures, produce carbon dioxide.

The biological leavening agents may be subdivided into at least three groups, yeasts, molds, and bacteria. Since molds such as *Mucor rouxii* may be used but rarely, just the yeasts and bacteria will be considered. Yeasts like *Saccharomyces*

⁵⁷ L. B. Jensen and L. S. Paddock, "Sausage Treatment with Lactobacilli," U. S. Patent 2,225,783 (1940).

cerevisiae act on the sugar present in the flour to convert it into carbon dioxide and alcohol. The carbon dioxide leavens the bread, the yeasts give it a certain flavor, and the alcohol evaporates during baking. This is known as baker's bread and is very light.

Bacterial leavening agents are used in making sauerteig, black bread, and salt rising bread. In salt rising bread and sauerteig about 2.0 to 2.5% of salt is added, while baker's bread has about 0.5%. Salt in this concentration does not exert a selective action on *Aerobacter levans*, *Escherichia coli* and *Lactobacillus bulgaricus*, the bacteria considered responsible for leavening and flavor in these breads. The first two organisms produce carbon dioxide, hydrogen, acetic and lactic acids, and some alcohol, while the last produces lactic acid.

These breads are heavy and sour as contrasted with the yeast or baker's bread. Pure cultures of *Clostridium welchii*, the organism causing gaseous gangrene, have been isolated from salt rising bread. Many other species of bacteria as well as yeasts have been isolated from these breads. Some believe that the fermentation is due to both yeasts and bacteria.

Black bread made from coarse wheat or rye flour appears to depend for its flavor and consistency upon at least three groups of organisms: yeasts to produce the gas; lactic or acetic bacteria to produce the acid which gives it the sour taste and smell; and peptonizing bacteria which change it from a thick to a more plastic state.

Chapter XIII

CHEMICAL PRESERVATIVES*

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I. INTRODUCTION AND DEFINITIONS

The use of chemical preservatives in foods by man is a very ancient practice, for long ago man learned to preserve his food by the use of various chemicals. In all likelihood, the discovery of the use of salt was accidental and was related to the finding of salt-encrusted carcasses in the deserts of Asia. The preservation of eggs by the Chinese by dipping them in water glass is a very old method.

About 50 years ago, the use of chemical preservatives in food was on the increase. Leach¹ mentions about a dozen mixtures which were commercially available. With the passage of the Wiley Food and Drug Act of 1906, however, and as a result of Wiley's active campaigning, the use of these agents became less common. Advances in other methods of preservation, production, and sanitation also tended to decrease their use.

As Monier-Williams² points out, chemical preservatives have the advantage of continuing to exert their preserving effect even though the food is exposed to air at ordinary temperatures, and the treatment of food in this way may be a more economical method than the application of heat or cold. Food preserved with chemicals, however, will remain sound only for a limited period of time, for the growth of micro-organisms is merely retarded and not entirely prevented. The greater the amount of preservative added, the longer will the decomposition be delayed. The mechanism by which chemical preservatives act has not been entirely elucidated but it is possible that food which is not heavily contaminated with bacteria may be preserved by chemicals because these chemicals prolong the lag phase of bacterial growth (see Volume I, page 366).

The use of chemicals to preserve food, although economical, permits both house-wife and commercial processor to handle and utilize fruits, vegetables, meats, and other foodstuffs in a much more unsanitary and careless manner than would be pos-

* The author wishes to state clearly that the mention of a particular substance in this chapter does not in any manner imply that he approves of the use of the substance as a chemical preservative.

¹ A. E. Leach, *Food Inspection and Analysis*. 1st ed., Wiley, New York, 1906.

² G. W. Monier-Williams, *Chemistry in Relation to Food*. Chem. Ind. Pamphlets, Ernest Benn, London, 1924.

sible without the use of such preservatives. Chemical preservation should never be used as a substitute for cleanliness in the processing of food. For this reason alone it is unwise to subscribe unqualifiedly to the contention that the unrestricted and indiscriminate use of chemical preservatives is entirely harmless. In addition, there is insufficient knowledge concerning their complete mode of action. Consequently, the use of chemicals for the preservation of foods should be rigidly controlled.

In 1911, Barnard³ set the following criteria which are still entirely applicable, for a completely adequate chemical preservative:

1. It must not under any reasonable conditions injure the health of the consumer.
2. It must not allow the utilization of unfit raw material.
3. Its use must not make possible the employment of careless and imperfect methods of manufacture.
4. It must be nonirritant.
5. It must be efficient in its action.
6. It must not retard the action of digestive enzymes.
7. It must have no tendency to decompose within the body into substances which have a greater toxicity than that of the preservative itself.
8. It should lend itself to simple methods of determination and thus simplify the control problem.

Preservatives are ordinarily defined as substances which have antiseptic properties under the conditions of use—that is, they are substances which inhibit the growth of microorganisms without necessarily destroying them. Effective inhibition of microbiological growth prevents spoilage of foods. However, this definition is too limited from a practical aspect. Spoilage may occur which has no relationship to the growth of microorganisms; for instance, there is spoilage which is attributed to oxidation or to the action of autolytic enzymes. Since substances which will prevent such spoilage must also be considered preservatives, preservatives are defined as chemical agents which serve to retard, hinder, or mask undesirable changes in food.

Many of the substances used as preservatives may in themselves be harmless or relatively harmless. Among these are sugar, salt, nitrates, vinegar, organic fruit acids, wood smoke, hops, and alcohol—all used in the preservation of foods. One would not ordinarily consider them as chemical preservatives, although they do have a bactericidal, germicidal, or antifermentative action. Chenowith⁴ classes these materials as common or kitchen preservatives in contradistinction to chemical preservatives. Sherman⁵ classes sugar, vinegar, wood smoke, and salt as substances with condimental properties as opposed to sodium benzoate, salicylic acid, boric acid, borax, sulfur dioxide, formaldehyde, etc., which he terms noncondimental agents. The word condiment originally meant a preservative. The action and use of these common kitchen or condimental substances has been discussed in several chapters, principally Chapters XI, XIII, and XXIII of Volume I and Chapters XII, XIX, and XXI of Volume II. These should be consulted.

³ H. E. Barnard, *Chem. Eng.*, 12, 104 (1911).

⁴ W. W. Chenowith, *Food Preservation*. Wiley, New York, 1930.

⁵ H. C. Sherman, *Food Products*. Macmillan, New York, 1933.

In conformance with such concepts, the term preservative for foods is defined by the British Food and Drug Act of 1928 as:

"'Preservative' means any substance which is capable of inhibiting, retarding, or arresting the process of fermentation, acidification, or other decomposition of food or of masking any of the evidences of any such process or of neutralizing the acid generated by any such process; but does not include common salt (sodium chloride), saltpeter (sodium or potassium nitrate), sugars, acetic acid, or vinegar, alcohol or potable spirits, spices, essential oils or any substance added to the food by the process of curing known as smoking."

In a broader sense, however, if these materials and others like them, as for example, lactose or lactic acid, are used to retard damage or to conceal inferiority, strict interpretation would imply that these, too, are chemical preservatives rather than kitchen preservatives. Thus, where lactic acid instead of vinegar is added to white horseradish colored with beet juice in order to preserve the red color of the beet juice, because lactic acid has less action on this color than has acetic acid, it becomes difficult to decide whether an inferiority is concealed or not. In the same light, if lactose or milk powder, or some similar material has been added to frozen egg yolks so that the yolks when thawed will not yield a gummy mass, the question arises whether or not the lactose or milk powder has been added because it is an inexpensive filler or is an antiflamentative agent, rather than an aid in the thawing step.

In the United States, as far as federal regulation is concerned no separate standards for food preservatives have been proposed. In unstandardized foods, they are covered by the general provisions of the Food, Drug, and Cosmetic Act of 1938, that is, preservatives are prohibited if the preservative is a poison (see page 133). In standardized foods they may be used only if recognized as an optional ingredient. However, many of the States and some municipalities have rigid prohibitions about the use of preservatives. The Federal Food, Drug, and Cosmetic Act requires the label declaration of chemical preservatives in food.

The reasons for the prohibition, declaration, and limitation of preservatives are clear. First, they may be used to conceal damage or inferiority, as in the case of the use of sulfites in meats; second, they may be unknown to the consumer, as in the case of undeclared benzoates in a foodstuff; and third, if maximum limits of preservative content are not enforced, the cumulative effect might be harmful.

In times of stress or of food shortage, every effort must be made to conserve food supplies.⁶ Consequently, the use of preservatives must be carefully re-examined so that those substances which are physiologically and toxicologically harmless may be used. However, the consideration as to whether or not they are being used as substitutes for cleanliness, as previously noted, must be a factor to be evaluated.

For example, certain preservatives were permitted in Germany. Regulations concerning them were published in 1932. These preservatives had to comply with the standards of the German Pharmacopoeia. The sale of mixtures of preservatives other than those mixtures appearing in the official list was prohibited, as was the sale of

⁶ M. B. Jacobs, *Chemical Analysis of Foods and Food Products*. Van Nostrand, New York, 1938, p. 102.

preservatives mixed with other substances, with the exception of mixtures containing salt, sugar, tartaric acid, citric acid, and mixtures of the ethyl and propyl esters of *p*-hydroxybenzoic acid with sodium carbonate. Preserved foodstuffs sold in packages had to be labeled "chemically preserved" or "chemically preserved with boric acid" when boric acid was present. The approved preservatives⁷ comprised the following, and were to be used in the amounts specified per 100 grams of foodstuffs:

Ethyl and propyl esters of p-hydroxybenzoic acid including their sodium compounds and their mixtures.—Fish and crustacean products, 50 mg.; salmon, 25 mg.; salmon substitute, 25 mg.; preserved eggs, liquid egg yolk, 800 mg.; margarine, 80 mg.; preserved vegetables, pickling liquors, 80 mg.; fruit preparations (other than cherry, orange, and lemon juices), 90 mg.; cherry juice, orange juice, lemon juice, 90 mg.; nonalcoholic drinks, 50 mg.; fruit pulp and fruit butter, 90 mg.; liquid fruit pectin, 90 mg.; confectionery, chocolates, 120 mg.; ices, 15 mg.; coffee extracts and substitutes, 100 mg.; malt extract with water content of 20–25% and in packages of 5 kilos and over, 50 mg.

Hexamethylenetetramine.—Fish and crustacean products, 25 mg., in addition to the above esters (50 mg.); fish roes, German roe, caviar, 100 mg.; crabs' claws, etc., 50 mg.

Hydrogen Peroxide.—Fish in jelly ("Bratmarinaden"), 200 mg. in jelly in addition to the esters (50 mg.).

Benzoic Acid.—Salmon substitute, 500 mg.; crabs' claws, etc., 500 mg. (alternative to hexamethylenetetramine); caviar, 500 mg. (alternative to hexamethylenetetramine); crabs, tinned crabs, 900 mg.; preserved eggs: liquid egg yolk, 1000 mg., or 1200 mg., of sodium benzoate (alternative to the esters); margarine, 200 mg. or 240 mg. of sodium benzoate (alternative to the esters); preserved vegetables, pickling liquors, 200 mg., or 240 of sodium benzoate (alternative to the esters); fruit preparations and juices (other than cherry, orange, and lemon juice), 180 mg. of sodium benzoate (or formic acid, sulfurous acid, potassium sulfite, or esters); cherry juice, orange juice, lemon juice, 180 mg. of sodium benzoate (or formic acid, sulfurous acid, potassium sulfite or esters); fruit pulp and fruit butters, 150 mg. (or 180 mg. of sodium benzoate (as alternative); liquid fruit pectin, 180 mg. of sodium benzoate; nonalcoholic drinks, 50 mg. of sodium benzoate (as alternative); chocolate and confectionery, 150 mg. (alternative to esters); ices, 100 mg. (alternative to esters); edible mustard, 150 mg.

Boric Acid.—Anchovies, 500 mg.; caviar, 500 mg. (alternative to hexamethylenetetramine); crabs, tinned crabs, 900 mg.; liquid egg yolk intended exclusively for use in fancy bakeries but not in the production of dietetic foods, 1500 mg.

Formic Acid (25% solution).—Fruit preparations and fruit juices other than cherry, orange, and lemon juices, 1000 mg. (alternative); cherry, orange, and lemon juices, 1600 mg. (alternative); liquid fruit pectin, 1000 mg. (alternative).

Sulfurous Acid.—Horse-radish preparations, 75 mg. (as SO₂), or 125 mg. of sodium bisulfite; fruit preparations and juices; also cherry, orange, and lemon juices, 125 mg.; or 435 mg. of potassium pyrosulfite (alternatives); fruit pulp and fruit butter, 125 mg. or 435 mg. of potassium pyrosulfite (alternatives); fruit juice used directly as a beverage, excepting grape juice, 12.5 mg.; dried fruit, 200 mg.; edible gelatin, 125 mg.

In the preparation of jams, marmalades, etc., benzoic acid, sodium benzoate, formic acid, or the esters mentioned above may be used in aqueous or alcoholic solution for wetting parchment paper used as covering for the product packed for sale.

II. CLASSIFICATION

Chemical preservatives may be classified in a number of ways. For instance, they may be grouped into (1) inorganic preservatives, and (2) organic preservatives and

⁷ Analyst, 59, 348 (1934).

sweeteners. In the first group, among the principal agents used are nitrates, nitrites, sulfites and sulfurous acid, borates, iodates, free chlorine, hypochlorites, and peroxides. In the second group, the principal agents are benzoates, formaldehyde, salicylates, formic acid, esters of *p*-hydroxybenzoic acid, propionic acid and its sodium and calcium salts, thiourea, and many others; the principal sweetening agents are saccharin and dulcin.

Chemical preservatives may also be classified according to their use or action, namely, as antiseptics, fungistats, germicides, antioxidants, neutralizers, stabilizers, emulsifiers, salt balance adjusters, firming agents, and coating agents, and in other categories. For the purposes of this chapter, it is preferable to discuss chemical preservatives under this type of classification.

III. BACTERIOSTATIC, FUNGISTATIC, OR GERMICIDAL AGENTS

1. Benzoates

Sodium benzoate, ammonium benzoate, and benzoates in general are among the principal agents used which have this action. Sodium benzoate and benzoic acid are listed as optional ingredients in several definitions and standards of identity promulgated by the Food and Drug Administration. To be more precise, benzoic acid is the effective agent, since sodium and ammonium benzoate must be used in acid media to be effective. The acidity of the medium in which the preservative works is very important. Thus a decrease in ϕH from 7 to 3.5 may increase five- to tenfold the antiseptic and bactericidal action. Rahn and Conn^{7a} have shown that benzoic acid, salicylic acid, and sulfurous acid are nearly 100 times as efficient antiseptics in strongly acid solution as they are in neutral solutions. With benzoic acid and salicylic acid only the undissociated acid is antiseptic, and the benzoate and salicylate ions have practically no effect on yeast. Benzoic acid is more effective against yeasts than against molds. It is generally added in the order of not more than 0.1%. The ability of cranberries to resist rapid deterioration is attributed to their benzoic acid content.

The use of benzoates in food was a troublesome question many years ago. The Wiley report of 1908 concluded that benzoates were highly objectionable and poisonous. On the other hand, the official Remsen⁸ Referee Board Report of 1909 concluded that sodium benzoate was relatively harmless. Folin,⁹ in commenting on this subject in 1914, stated: "Benzoic acid and sodium benzoate are the most promising of the modern chemical preservatives, though we are not yet justified in saying that they are strictly harmless." He added succinctly: "Competent and disinterested experimentation with different chemical preservatives is much needed, and should be encouraged. It is not clear that the use of even a somewhat harmful preservative

^{7a} O. Rahn and J. E. Conn, *Ind. Eng. Chem.*, 36, 185 (1944).

⁸ I. Remsen, "Influence of Sodium Benzoate, U. S. Dept. Agr. Rept. 88 (1909).

⁹ O. Folin, *Preservatives and Other Chemicals in Foods: Their Use and Abuse*. Harvard Univ. Press, Cambridge, 1914.

might not on the whole be desirable in the case of certain products, which, without the use of a preservative, would be eaten in various stages of decay."

The bacteriostatic action of benzoic acid can be increased by the introduction of a side chain. Thus, phenylbutyric acid is about four times more effective as a bacteriostatic agent than is benzoic acid.

An interesting application of benzoic acid as a preservative is its use in antiseptic ices. Benzoic acid forms an eutectic mixture with water. The mixture freezes at about 31.9° F. and contains 0.16% benzoic acid. Since it is an eutectic mixture, the benzoic acid is distributed uniformly throughout the ice, in contradistinction to sodium nitrite ice (page 407) in which the sodium nitrite is scattered at random in the ice and is more concentrated in the core. Benzoic acid ice, however, is not so effective in preserving fish as is sodium nitrite ice.

p-Hydroxybenzoates.—The introduction of substituted groups in the para position also increases the effectiveness of benzoic acid. Thus, the esters of *p*-hydroxybenzoic acid have found increasing use as preservatives. In Germany, as noted, they are familiar chemical agents. The methyl, ethyl, and propyl esters are possibly the most commonly used. As the side chain increases, the effectiveness of these compounds is increased. Only one-tenth as much *n*-butyl-*p*-hydroxybenzoate (a preservative used in cosmetics) is required as benzoic acid or salicylic acid to produce the same effect.

2. Monochloroacetic Acid

Monochloroacetic acid, CH_2ClCOOH , which has been banned by the Food and Drug Administration as a preservative for foods, has strong advocates for its use for this purpose. Leake¹⁰ states that it is well suited to this purpose because it gradually splits to form such innocuous compounds as sodium acetate and sodium chloride. This process takes about one month. He also found that the optimum amount for stabilization in commercial practice, namely, 300 parts per million, presents no hazard to health. However, Joslyn and Cruess¹¹ hold that the Food and Drug Administration ruling is wise because in their opinion sodium benzoate is a better preservative for orange juice and apple juice than is monochloroacetic acid. Fabian and Bloom¹² conclude that benzoic acid and monochloroacetic acid are about equal in preservative action. The work of Wilson^{12a} indicates that little if any loss of monochloroacetic acid occurs when this preservative is used with fruit-type and non-fruit-type carbonated beverages in 19 months, pasteurized or unpasteurized apple juice in 13 months, or canned orange juice and grapefruit juice in 30 months.

3. Propionates, Fatty Acids, and Mold Inhibitors

The use of fatty acids and some of the salts of fatty acids as mold inhibitors has been developed to a great extent. In general, most of the fatty acids containing from 1

¹⁰ C. Leake, *Food Industries*, 14, No. 6, 102 (1942).

¹¹ M. A. Joslyn and W. V. Cruess, *Food Industries*, 14, No. 9, 110 (1942).

¹² F. W. Fabian and E. F. Bloom, *Fruit Products J.*, 21, 292 (1942).

^{12a} J. B. Wilson, *J. Assoc. Official Agr. Chem.*, 27, 195 (1944).

sweeteners. In the first group, among the principal agents used are nitrates, nitrites, sulfites and sulfurous acid, borates, iodates, free chlorine, hypochlorites, and peroxides. In the second group, the principal agents are benzoates, formaldehyde, salicylates, formic acid, esters of *p*-hydroxybenzoic acid, propionic acid and its sodium and calcium salts, thiourea, and many others; the principal sweetening agents are saccharin and dulcin.

Chemical preservatives may also be classified according to their use or action, namely, as antiseptics, fungistats, germicides, antioxidants, neutralizers, stabilizers, emulsifiers, salt balance adjusters, firming agents, and coating agents, and in other categories. For the purposes of this chapter, it is preferable to discuss chemical preservatives under this type of classification.

III. BACTERIOSTATIC, FUNGISTATIC, OR GERMICIDAL AGENTS

1. Benzoates

Sodium benzoate, ammonium benzoate, and benzoates in general are among the principal agents used which have this action. Sodium benzoate and benzoic acid are listed as optional ingredients in several definitions and standards of identity promulgated by the Food and Drug Administration. To be more precise, benzoic acid is the effective agent, since sodium and ammonium benzoate must be used in acid media to be effective. The acidity of the medium in which the preservative works is very important. Thus a decrease in *pH* from 7 to 3.5 may increase five- to tenfold the antiseptic and bactericidal action. Rahn and Conn^{7a} have shown that benzoic acid, salicylic acid, and sulfurous acid are nearly 100 times as efficient antiseptics in strongly acid solution as they are in neutral solutions. With benzoic acid and salicylic acid only the undissociated acid is antiseptic, and the benzoate and salicylate ions have practically no effect on yeast. Benzoic acid is more effective against yeasts than against molds. It is generally added in the order of not more than 0.1%. The ability of cranberries to resist rapid deterioration is attributed to their benzoic acid content.

The use of benzoates in food was a troublesome question many years ago. The Wiley report of 1908 concluded that benzoates were highly objectionable and poisonous. On the other hand, the official Remsen⁸ Referee Board Report of 1909 concluded that sodium benzoate was relatively harmless. Folin,⁹ in commenting on this subject in 1914, stated: "Benzoic acid and sodium benzoate are the most promising of the modern chemical preservatives, though we are not yet justified in saying that they are strictly harmless." He added succinctly: "Competent and disinterested experimentation with different chemical preservatives is much needed, and should be encouraged. It is not clear that the use of even a somewhat harmful preservative

^{7a} O. Rahn and J. E. Conn, *Ind. Eng. Chem.*, 36, 185 (1944).

⁸ I. Remsen, "Influence of Sodium Benzoate, U. S. Dept. Agr. Rept. 88 (1909).

⁹ O. Folin, *Preservatives and Other Chemicals in Foods: Their Use and Abuse*. Harvard Univ. Press, Cambridge, 1914.

might not on the whole be desirable in the case of certain products, which, without the use of a preservative, would be eaten in various stages of decay."

The bacteriostatic action of benzoic acid can be increased by the introduction of a side chain. Thus, phenylbutyric acid is about four times more effective as a bacteriostatic agent than is benzoic acid.

An interesting application of benzoic acid as a preservative is its use in antiseptic ices. Benzoic acid forms an eutectic mixture with water. The mixture freezes at about 31.9° F. and contains 0.16% benzoic acid. Since it is an eutectic mixture, the benzoic acid is distributed uniformly throughout the ice, in contradistinction to sodium nitrite ice (page 407) in which the sodium nitrite is scattered at random in the ice and is more concentrated in the core. Benzoic acid ice, however, is not so effective in preserving fish as is sodium nitrite ice.

p-Hydroxybenzoates.—The introduction of substituted groups in the para position also increases the effectiveness of benzoic acid. Thus, the esters of *p*-hydroxybenzoic acid have found increasing use as preservatives. In Germany, as noted, they are familiar chemical agents. The methyl, ethyl, and propyl esters are possibly the most commonly used. As the side chain increases, the effectiveness of these compounds is increased. Only one-tenth as much *n*-butyl-*p*-hydroxybenzoate (a preservative used in cosmetics) is required as benzoic acid or salicylic acid to produce the same effect.

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¹² F. W. Fabian and E. F. Bloom, *Fruit Products J.*, 21, 292 (1942).

^{12a} J. B. Wilson, *J. Assoc. Official Agr. Chem.*, 27, 195 (1944).

to 14 carbon atoms are effective mold inhibitors.¹³ Of these acids, propionic acid and its salts are commonly used in the prevention of mold and rope in bread. Mycoban, a trade name for one of these mixtures, consists of a salt of propionic acid mixed with small amounts of ammonium carbonate.

The use of propionates for the protection of cheese against surface mold growth is increasing. In one method, packaged cheese is immersed in a 10% solution of calcium propionate and is subsequently held at 50° F. or less. Greater inhibiting effect is obtained by the use of a mixture consisting of 5 parts of 10% calcium propionate and 1 part of 10% propionic acid.

To prevent the growth of mold in soft cheese such as cottage cheese, pot cheese, cream cheese, and Neufchatel cheese, about 0.15% of calcium or sodium propionate is sometimes used. Dipping the containers, caps, or wrappers covering these products in solutions of these propionates is also effective. However, the use of propionates and other mold inhibitors in sour cream is prohibited.

As early as 1850, vinegar was used to reduce rope infection in bread. Monocalcium acid phosphate also was used to lower the pH; and thus both acetic acid and the phosphate, both ineffective against mold, could be used to reduce rope troubles. Butyric acid and valeric acids are good mold inhibitors but cannot be used because of their odor. While sodium propionate, as noted above, is a good mold inhibitor, sodium acetate has practically no effect. Sodium diacetate, $\text{CH}_3\text{COONa}\cdot\text{CH}_3\text{COOH}$, a peculiarly bound compound of acetic acid and sodium acetate, exhibits both mold and rope retarding action.¹⁴

4. Propylene Glycol

Propylene glycol, $\text{CH}_3\text{CHOHCH}_2\text{OH}$, is a colorless, odorless compound which has been advocated as a mold inhibitor. For this purpose, it is better than glycerol and equal to ethyl alcohol. It has been proposed to use this compound as a spray in air because it has a marked and rapid killing action on bacteria suspended in air. However, Robertson¹⁵ points out that propylene glycol possesses a relatively low germicidal action *in vitro*. Therefore, if this substance is to be used as a food preservative it must be used under conditions in which its air sterilizing properties are effective, that is, as a germicidal mist or spray. Such use can probably be found by employing it in warehouse refrigerators, storage warehouses, and similar establishments. It may also be of value in the production plant itself as a means of diminishing the amount of contamination to which a food product may be exposed.

5. Quaternary Ammonium Compounds and Other Organic Preservatives

Among the other organic chemicals which have been used for bacteriostatic action in foods may be mentioned formaldehyde, salicylic acid, formic acid, *o*-chlorobenzoic

¹³ C. Hoffman, R. T. Schweitzer, and G. Dalby, *Food Research*, 4, 539 (1939).

¹⁴ E. F. Glabe, *Food Industries*, 14, No. 2, 46 (1942).

¹⁵ O. H. Robertson, *Science*, 97, 495 (1943).

acid, *p*-chlorobenzoic acid, cinnamic acid, and some phenols. Many of these substances are sold under trade names. Table 32 lists some of the common trade names of preservatives and their principal component. Rideal¹⁶ mentions the use of phenol in pickling brine. Formaldehyde, years ago, was a common preservative for milk and meat. Salicylic acid was often used in jams and jellies to prevent the formation of mold.

TABLE 32
TRADE NAMES OF CHEMICAL PRESERVATIVES

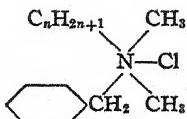
Trade name	Chemical name	Trade name	Chemical name
Abrastol.....	Calcium α -monosulfonate- β -naphthol	Nipagin.....	Methyl <i>p</i> -hydroxybenzoate
Asaprol.....	Calcium α -monosulfonate- β -naphthol	Nipahin.....	Ethyl <i>p</i> -hydroxybenzoate
Aseptoforms.....	Esters of <i>p</i> -hydroxybenzoic acid	Nipasol.....	Propyl <i>p</i> -hydroxybenzoate
Butoben.....	<i>n</i> -Butyl- <i>p</i> -hydroxybenzoate	Nipicide.....	Chlorine releasing compound
Ceprym chloride.....	Cetylpyridinium chloride	Onyx BTC.....	Alkyldimethylbenzylammonium chlorides
Cetavlon.....	Cetyltrimethylammonium bromide	Paragerm.....	Methylpropylidiphenol- <i>p</i> -oxybenzoate
CTAB.....	Cetyltrimethylammonium bromide	Parasept, butyl.....	Butyl, ethyl, methyl, and ethyl, methyl propyl <i>p</i> -hydroxybenzoates and propyl
Dowicide B.....	Sodium 2,4,5-trichlorophenate	Phemerol.....	<i>p</i> -tert-Octylphenyldiethoxydimethylbenzylammonium chloride
Dowicide G.....	Sodium pentachlorophenate	Preservaline.....	Sodium sulfite, also formaldehyde
Esteril.....	Higher esters of <i>p</i> -hydroxybenzoic acid	Quartamon.....	Chlorobenzyl deriv. of alkyl amide of dimethylaminoacetic acid
Jiffy-Pak.....	Potassium metabisulfite	Quartol.....	Cetylpyridinium bromide
Merfène.....	Phenylmercuric borate	Roccal.....	Alkyldimethylbenzylammonium chlorides
Mikrobin.....	<i>p</i> -Chlorobenzoic acid, sodium salt	Solbrol.....	Methyl <i>p</i> -hydroxybenzoate
Moldex.....	Methyl <i>p</i> -hydroxybenzoate	Zephiran.....	Alkyldimethylbenzylammonium chlorides
Moldol.....	Sodium benzoate and benzoic acid mixture	Zephirol.....	Alkyldimethylbenzylammonium chlorides
Mycoban.....	Propionic acid salt (calcium or sodium)	505.....	Monochloroacetic acid
Nipacombin-A.....	Propyl and ethyl <i>p</i> -hydroxybenzoate sodium salt, 6:4 combination		

In more recent years, these organic chemicals have been abandoned for the use of other agents, principally quaternary ammonium compounds. It was mentioned on page 214 that among the chemicals used for washing, detergency, and plant sanitation were the surface-active agents. A large number of these surface-active agents have been developed for use as detergents and are generally classified into three groups: (1) the cationic compounds such as the alkyldimethylbenzylammonium chlorides in which the hydrophobic group is in the cation; (2) the anionic compounds such as sodium lauryl sulfate in which the hydrophobic group is in the anion; and (3) the unionized compounds such as the polyethers and polyglycerol esters. The detergents of the cationic group are more effective germicidal agents than the anionic group.¹⁷ For

¹⁶ S. Rideal, *Disinfection and the Preservation of Food*. Wiley, New York, 1903.

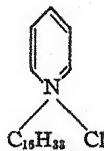
¹⁷ Z. Baker, R. W. Harrison, and B. F. Miller, *J. Exptl. Med.*, 73, 249 (1941); 74, 611 (1941).

this reason there has been an increasing tendency to introduce them as food preservatives. Thus, Harshbarger^{17a} compared the action of sodium benzoate, sodium benzoate and added glycine, sodium and calcium propionates, and a germicide consisting of alkyldimethylbenzylammonium chlorides. As much as 3% of the propionates and the germicide apparently caused no ill effects in the diets of rats. The alkyldimethylbenzylammonium chlorides are sold under a number of trade names, such as Zephiran, Roccal, Onyx BTC, and Zephirol. The alkyl groups range from C_8H_{17} to $C_{18}H_{37}$; but because of the standardized method of manufacture¹⁸ the average molecular weight is 357.5.

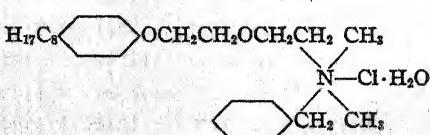


Alkyldimethylbenzylammonium chlorides

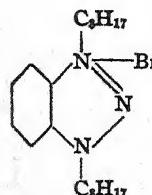
The alkyldimethylbenzylammonium chlorides are related to the surface-active agents.^{19, 20} They may derive their germicidal power and hence their preservative effect by the lowering of the surface tension of the cells of microorganisms. The effectiveness of these agents is reduced in the presence of nitrogenous material, so that relatively larger amounts of the alkyldimethylbenzylammonium chlorides must be used in the food products themselves. This may, in turn, have an adverse effect on the odor, flavor, and appearance of the food product. The inhibition of bacterial metabolism which is caused by cationic and anionic detergents is prevented by lecithin, cephalin, and sphingomyelin. Hence germicidal quantities of these detergents are not effective in the presence of phospholipids.^{20a}



Cetylpyridinium chloride



p-tert-Octylphenyldiethoxydimethylbenzylammonium chloride monohydrate



1,3-Di-*n*-octylbenztriazolium bromide

^{17a} K. E. Harshbarger, *J. Dairy Sci.*, 25, 169 (1942).

¹⁸ M. E. Auerbach, *Ind. Eng. Chem., Anal. Ed.*, 15, 492 (1943).

¹⁹ *Ind. Eng. Chem.*, 35, 126 (1943).

²⁰ F. D. Snell, *Ind. Eng. Chem.*, 35, 197 (1943).

^{20a} Z. Baker, R. W. Harrison, and B. F. Miller, *J. Exptl. Med.*, 74, 621 (1941).

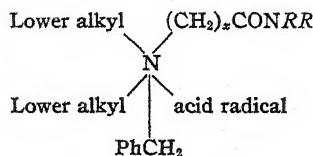
An analogous type of compound is *p*-*tert*-octylphenyldiethoxydimethylbenzylammonium chloride (Phemerol). Other compounds that have been mentioned for preservative use are cetylpyridinium chloride and 1,3-di-*n*-octylbenztriazolium bromide.

Some other cationic detergents which may possibly be used as preservatives are:

Catol.....	Alkyltriethylammonium chloride
Damol.....	<i>N,N,N',N'</i> -Tetramethyl <i>N,N'</i> -didodecyl- β -hydroxypropylene-diammonium bromide
Emulsol-605.....	Alkyltrimethylammonium chloride
Emulsol-606.....	Lauryl ester of glycine hydrochloride
Emulsol-607.....	Alkylpyridinium chloride
Emulsol-609.....	Lauryl ester of α -aminobutyric acid hydrochloride
Emulsol-660 B.....	Laurylpolydiminium iodide
Hydrocide.....	Alkylhydroxybenzylidemethylammonium phosphate
Retarder LA.....	Stearyltrimethylammonium bromide
Triton K-12.....	Cetyltrimethylbenzylammonium chloride
Triton K-60.....	Lauryldimethylbenzylammonium chloride

The alkyl group of Emulsol-605, Emulsol-607, and Catol is $C_{11}H_{28} \cdot COO \cdot CH_2 \cdot CH_2 \cdots NH \cdot CO \cdot CH_2$.

A patent²¹ has been issued for quaternary ammonium compounds having the general type formula:



where x stands for 1 or 2, at least one R stands for a higher molecular weight aliphatic hydrocarbon radical, the other R standing for hydrogen, and the aromatic nucleus of the benzyl group being substituted by at least one substituent of the group consisting of alkyl, alkoxy, halogen and nitro radicals. These compounds have been recommended for preserving foods such as fruits, vegetables, or meat. Among them may be mentioned: *p*-nitrobenzyldimethylammonium chloride-*N*-acetyldodecylamide; *p*-methylbenzyldimethylammonium chloride-*N*-acetyldodecylamide; *p*-chlorobenzylidemethylammonium chloride-*N*-acetyldodecylamide; *p*-methoxybenzyldimethylammonium chloride-*N*-acetyldodecylamide; *o*-chlorobenzylidemethylammonium chloride-*N*-acetyl methyl dodecylamide; *m*, *p*-dichlorobenzylidemethylammonium chloride-*N*-acetyldodecylamide; and *p*-nitrobenzyldimethylammonium chloride-*N*-propiyldodecylamide.

There are strong advocates for the use of phenylmercuric compounds as preservatives in cosmetics. They have also been recommended for use in foods; but it is difficult to see what can be gained by their use here. Phenylmercuric compounds such as phenylmercuric borate, acetate, nitrate, benzoate, and chloride under certain conditions have 10,000 times the cytostatic action of phenol. This action, however, is considerably diminished in the presence of protein.

Organic acids such as lactic acid, citric acid, tartaric acid, and acetic acid are used

²¹ U. S. Patent 2,317,999 (1943).

in food preservation. The role of some of these acids has been previously discussed. See page 364. The use of lactic acid in preservation of white horse-radish colored with beet juice is mentioned on page 396. Citric and lactic acids are effective for the preservation of fish only when the fish are immersed for sufficient time to permit the muscle to reach a *pH* of 5. The action is similar to that in acid-cured fish like marinated herring. This treatment is better than nitrite-brine solution (see page 407) but causes undesirable changes in the fish.

Tarr²² mentions the use of chloroform, hexamethylenetetramine, carbon disulfide, glycerol, alcohol, and chloropicrin, in addition to some of the other chemicals discussed in this chapter, for the preservation of fish. Sodium chloride brine containing 0.70% of chloroform effected a marked improvement in the keeping quality of fish processed in such brines. Tarr suggests that chloroform has the advantage of evaporating during storage.

6. Antibiotic Substances

The use of antibiotic substances, particularly penicillin, for the control of disease, has increased in recent years. These antibiotic substances, among which may be mentioned, in addition to penicillin, gramicidin (tyrothricin), pyocyanine, and tyrocidin, are widely distributed in nature and have the ability to inhibit the growth of bacteria in very small concentrations. It is conceivable that they may be incorporated in foodstuffs to act as preservatives. Thus, as pointed out in Volume I, page 370, there are substances in cabbage, onions, and turnips which are toxic to *Escherichia coli* and *Bacillus subtilis*. It is possible that spices such as cloves, thyme, and coriander owe their preservative action to the presence of antibiotic substances.

7. Smoking

The primary purpose of smoking meat, meat products, fish, and fish products is the preservation of the food material; the secondary purpose is the increase of palatability. It is the consensus of opinion of various authorities that the greater preservative action of the smoking process results from the drying action of the smoke rather than from that of the chemical preservatives in the smoke.

The slow burning of the sawdust of hardwoods such as hickory, juniper bush, maple, and birch probably produces a smoke containing some formaldehyde, creosote, phenols, and pyroligneous acid. The heat of the smoking process and the chemicals present in the smoke assist in coagulating the proteins of the exterior of the product being processed. In addition, the action of the nitrite and nitrate present is accelerated.

There is little question that the addition to the sawdust used for smoking of chemical preservatives such as wood creosote, pyroligneous acid (crude wood acetic acid), and patented articles consisting mainly of these chemicals, even though they are the products of the destructive distillation of hardwoods, is done mainly to hasten and

²² H. L. A. Tarr, *Proc. Inst. Food Tech.*, 1940, p. 145.

shorten the smoking step. This is undesirable because it reduces the amount of dehydration which is the principal action desired in smoking.

An even less desirable practice is that of artificial smoking, in which the product is merely dipped into a solution of the aforementioned chemicals, or is painted with such a solution. In such a process no attempt is made to dry the food product other than to permit it to dry spontaneously. This procedure has practically no preservative action.

8. Sulfur Dioxide and Sulfites

The principal inorganic substances, other than nitrates and nitrites, used as chemical preservatives are the sulfites. Sulfur dioxide is one of the oldest antiseptics known. In Augsburg, in 1400, a special law was passed forbidding the sulfuring of casks. In London, in 1635, certain wines were pronounced unwholesome because they contained sulfur.²³

Sulfur dioxide and sulfites are used principally for the preservation of acid fruits and vegetables. These substances are more effective against molds than yeasts. The process of sulfuring and the use of metabisulfites has an inactivating affect on some of the vitamins of fruits and vegetables, and detracts appreciably from the palatability of these foodstuffs. This loss of palatability is apparent even after the sulfur dioxide has been boiled out. The use of sulfites as preservatives is discussed on pages 294 *et seq.*, and 309.

As mentioned on page 398, undissociated sulfurous acid is an efficient antiseptic only in strongly acid solution.²⁴ The SO_3^{--} ion has no effect while HSO_3^- inhibits the growth of *E. coli* in concentrations of the order of 10 mg. per 100 ml. The growth of yeast is not inhibited by HSO_3^- .

The literature supports the view that combined sulfurous acid has little or no preservative effect. It has been found that the addition of dextrose and other substances reduces the germicidal effect of sulfurous acid. Thus, sulfited, concentrated citrus juices contain a lower proportion of free sulfurous acid than unconcentrated juices because of the higher concentration of sulfurous acid-fixing substances, such as dextrose, present in the concentrates. The effect of the total sulfurous acid content on the combined sulfur dioxide is slight or negligible. The proportion of combined sulfurous acid increases with increase in dextrose content. There is no correlation between either the citric acid content or $p\text{H}$ value and the proportion of free sulfurous acid. Fermentation appears to be more frequent in concentrated juices because of the lower free sulfurous acid content. It is probable that 500 p. p. m. of free sulfurous acid would be adequate in preserving concentrated juices for which a total sulfurous acid content of 2000–2500 p. p. m. is required, particularly for approximately fourfold concentrated orange and grapefruit juices. More is necessary if slight fermentation has begun. Once fermentation in a juice becomes vigorous, however, it usually can-

²³ S. Rideal, *Disinfection and the Preservation of Food*. Wiley, New York, 1903.

²⁴ O. Rahn and J. E. Conn, *Ind. Eng. Chem.*, 36, 185 (1944).

not be arrested by the addition of even large amounts of sulfurous acid. This is attributed in part to a combination between sulfurous acid and, presumably, acet-aldehyde, as shown by the small increase in the free sulfurous acid content. Downer²⁵ suggests that concentrated juices imported for use in soft drinks in Great Britain contain total sulfurous acid contents calculated as that of the normal natural juice multiplied by the degree of concentration of the juice in question.

The following process is permissible for shipping sulfured fruits to Great Britain but is not permissible for fruits sold in the United States. Sufficient sulfur dioxide gas is run into 378 lbs. of water to increase the weight to 400 lbs., yielding a specific gravity of 1.025. Generally, the fruit is prepared for preservation by this sulfur dioxide method in the same manner as for canning or cold packing. The fruit must be softened sufficiently to permit penetration by the sulfur dioxide. Before packing, 5 lbs. of sulfur dioxide solution are placed in each barrel. The hot mass is run into the barrel to within 2-3 in. of the bung hole. After filling, 5 lbs. more of sulfur dioxide solution are added, and then the barrel is closed and rolled to mix the contents thoroughly.

While, in general, sulfur dioxide in fruits is eliminated by volatilization during cooking so that only 3 or 4 p. p. m. remain, federal regulations permit about 200 p. p. m. in fruits for sale for direct consumption. In the United Kingdom, it is necessary to reprocess fruit shipped as noted above to below the minimum of 7 p. p. m.

Woodroof and Cecil²⁶ stress the necessity for thorough and repeated mixing in order to equalize the concentration of the sulfite throughout the container. They found that complete penetration of the preservative took place in 2-24 hrs. depending upon the kind of fruit, the degree of ripeness, and the firming agent used. Penetration into firm fruits such as Young dewberries was slower than with soft fruits such as peaches. It was more rapid with very ripe fruits than with green fruits, and it was more rapid when no firming agent was used. See page 417.

The removal of sulfur dioxide from preserved fruit is not so simple as may at first appear. Thus, in the experiments cited above, the sulfur dioxide content was reduced from 2200 to 200 p. p. m. by boiling in a steam-jacketed kettle for 20 min., or in a covered stewpan for 45-60 min. or in an open stewpan for 60-120 min. Mechanical stirring and artificial boiling proved to be too slow to be practical for the removal of sulfur dioxide.

Sodium sulfite itself has been used as a preservative for meat. Actually, in such instances it is doubtful if the sulfite does have any preservative action. It is generally incorporated with chopped meat which is in an incipient state of decomposition and actually serves to bring out a red color in the meat, tending to make the meat appear fresh. When incorporated in pickling brine, however, to the extent of about 0.1%, it has been shown that sulfites do have a retarding action on the spoilage of fish. This type of brine gives the processed fish an unpleasant odor.

An interesting application of the use of sodium sulfite as a preservative is in the

²⁵ A. W. E. Downer, *J. Soc. Chem. Ind.*, **62**, 124 (1943).

²⁶ J. G. Woodroof and S. R. Cecil, *Fruit Products J.*, **22**, 132 (1943).

production of dried cabbage²⁷ of high culinary quality and nutritive value. Blanching cabbage by scalding for 2 to 3 min. in a volume of 0.22% sodium sulfite solution (0.22% $\text{Na}_2\text{SO}_3 \cdot 7\text{H}_2\text{O}$) just sufficient to cover the cabbage yielded a final dried product without noticeable loss of color, flavor, texture, or vitamin C.

Potassium metabisulfite, also known as potassium pyrosulfite, $\text{K}_2\text{S}_2\text{O}_5$, and its analogous sodium salt are common preservatives. One tablet preparation consisting of potassium pyrosulfite and lactose is sold under the trade name of Jiffy-Pak. It is recommended as a quick and easy method of home canning. It is used somewhat along the following lines. The fruit or tomatoes are washed. Small fruits, berries, cherries, and plums can be packed whole, but pears and apples must be peeled, cored, and quartered before packing. Tomatoes can be packed whole or sliced. The product is placed in jars compactly, covered with a solution of metabisulfite, and the cover is screwed on tightly. The jars should be stored in a cool, dark place. The fruit and tomatoes must be cooked before use. Fruit juices can also be preserved with the use of this chemical.

9. Oxidizing Agents

The use of nitrates and nitrites in the preservation of meats is discussed as a factor in the curing of meats. See pages 675 *et seq.* The activation of these compounds by bacterial enzyme systems has been discussed in Volume I, page 455. It is customary to consider the incorporation of nitrite in brine solution used in meat curing as performed for condimental purposes.

No such interpretation can be placed on the incorporation of sodium nitrite in ice to be used for the preservation of fish. Crushed ice containing various types of chemical preservatives is known as "antiseptic ice." Tarr²⁸ found that bacterial spoilage in dressed halibut, pink salmon, and black cod was retarded more effectively by packing these fish in ice containing 0.05–0.1% sodium nitrite than when they were packed in ordinary ice or in ice containing benzoic acid. See page 399. Because of the high solubility of sodium nitrite in water, it is not feasible to use an eutectic ice containing this chemical as is the case with benzoic acid; but by eliminating aeration during the freezing and drainage of the core a variable proportion of nitrite can be occluded in all parts of the ice block. When the block is crushed, the concentration of nitrite is made more uniform. Nitrites probably owe their effectiveness as preservatives to their high solubility in water and consequently to their rapid penetration of fish muscle. Nitrites cause a yellow discoloration on the white side of halibut but do not affect the appearance of cod or salmon.

Brine solution containing 0.05–0.2% of sodium or potassium nitrite is more effective than brine containing benzoates, in the preservation of fresh and smoked fish fillets which have been immersed in these brines. Thus a brief dipping for a period of 5 min. in brine containing 0.1–0.6% sodium nitrite at 32–35° F., which will not permit

²⁷ R. J. L. Allen, J. Barker, and L. W. Mapson, *J. Soc. Chem. Ind.*, 62, 145 (1943).

²⁸ H. L. A. Tarr, *Proc. Inst. Food Tech.*, 1940, p. 145.

the fish to absorb more than 200 p. p. m., will cause a marked decrease in the rate of bacterial spoilage.

Chemicals such as potassium bromate, potassium iodate, ammonium persulfate, calcium peroxide, and other peroxides are incorporated with yeast or with improvers in order to activate the yeast. These substances are termed yeast nutrients or yeast foods. They probably act as oxidative inhibitors of wheat proteinase but they must also have some preservative action because they are oxidizing agents. The use of these substances is discussed in connection with the manufacture of bread. See pages 489 *et seq.*

The use of bleaching agents for flour is described in Volume I, page 696 *et seq.* Oxides of nitrogen, chlorine, nitrosyl chloride, nitrogen trichloride, and one part by weight of benzoyl peroxide mixed with not more than six parts by weight of a mixture of either potassium alum or calcium sulfate and magnesium carbonate may be used. Many of these substances unquestionably have a bacteriostatic action. This is well illustrated by the use of benzoyl peroxide as a germicide.

Hydrogen peroxide has been advocated as a preservative for milk and milk products. One of the advantages claimed is that it breaks down to harmless substances, water and oxygen. There is a British patent for its use in the preservation of rindless cheese. It has occasionally been found in milk products, for instance, in chocolate milk drinks. Tarr mentions the use of hydrogen peroxide in antiseptic ice for the preservation of fish in transit, and in brine solution in the production of fish fillets. Its preservative action was transient.

Antiseptic ice containing ozone has been used for the preservation of fish. This is another variation of the use of an oxidizing agent for bactericidal purposes. Ozone has also been used for the destruction of air-borne bacteria and mold spores in food processing plants.

The use of sodium hypochlorite solution as a wash for apples and some other fruits in order to inhibit mold growth is a commercial practice. Along similar lines is the addition of sodium hypochlorite or organic compounds capable of releasing chlorine to the ice used for icing fish in transit.

10. Fluorides

Occasionally fluorides and other analogous poisonous compounds such as fluosilicates and fluoborates are used as preservatives in foods. Rideal²⁹ mentions that fluosilicic acid was even patented as a preservative for eggs. The amount of fluorides in food is controlled by the Food and Drug Administration tolerance, which is set at 2 parts per million.

11. Borates

Borates and boric acid were commonly used as preservatives years ago, particularly in milk, cream, butter, margarine, liquid eggs, and fish. Solutions of boric acid

²⁹ S. Rideal, *Disinfection and the Preservation of Food*. Wiley, New York, 1903.

were injected near the ham bone to prevent sours in pickling. This practice was employed over 50 years ago. The chemical was merely dusted over the food product. Since boric acid and borates exert a weak action on bacteria, relatively large amounts have to be used. The use of as much as 11, 9, and 7 g. per lb. in margarine, butter, and bacon, respectively, was reported in England.³⁰ Usually the amount did not exceed 2.2 g. per lb. In 1917 in Great Britain, an order was issued which restricted the amount permissible in cream to 0.4%; and in 1928 the use of boron compounds as preservatives was prohibited. As noted on page 397, the limited use of these substances is permitted in Germany.

12. Ultraviolet Light

It is appropriate to mention, in connection with the use of chemical agents for the preservation of foodstuffs by killing molds and bacteria, the use of ultraviolet light. It has been shown that ultraviolet light of definite wave length does have bacteriostatic and fungistatic properties. To control surface mold growth, several food industries have adopted the use of lamps, such as 15 watt hot-cathode mercury-vapor lamps, producing ultraviolet rays. Thus, several bakeries now irradiate the air of the dough- and proofrooms to kill air-borne spores and thus prevent contamination of the product. Another use of ultraviolet light in bakeries is the irradiation of the knives of the slicing machine and of the room where the bread is packaged, as a means of controlling mold in sliced bread. Ultraviolet light has also been used for the control of the surface mold growth of packaged cheese and for the reduction of bacterial contamination in fish. It is to be stressed that ultraviolet light can be used only for the control of foodstuffs in good condition. Once mold and bacterial contamination is serious, the organisms have generally penetrated into the flesh or interior portion of the foodstuffs and are thus no longer exposed to the rays, which cannot penetrate the foodstuffs. Poor results are therefore generally obtained with cheese and cheese products.

Other uses of ultraviolet light are for the irradiation of milk for the production of vitamin D milk (see page 632) and for the tenderizing of meat. In the latter instance, the ultraviolet light, in preventing spoilage caused by bacteria and mold, speeds up the enzymatic action by permitting storage at the relatively high temperature of 60° F. with a relative humidity of 85 to 90%. One objection to this method of tenderizing is that the fat of the meat tends to become rancid, a rancidity attributed to the ozone formed by the ultraviolet radiation although it may be due to the radiation itself.

IV. ANTIOXIDANTS

1. For Oils

A principal type of food spoilage in oil bearing or fatty foods is the development of rancidity. Among the foods likely to become rancid are the edible oils and fats and oil bearing foods such as peanut butter, potato chips, nuts, coffee, dried milk products,

³⁰ *J. Am. Med. Assoc.*, 83, 1699 (1924).

corn meal, whole-wheat flour, biscuits, crackers, and some kinds of breakfast foods. This type of food spoilage often cannot be prevented by any of the means of preservation previously mentioned, that is, by dehydration, freezing, hermetic sealing (except in certain instances of packing under vacuum), and fermentation methods.

Rancidity may develop as a result of oxidative, hydrolytic, or ketonic degradation, but is generally attributed to the oxidative type, which may be induced and accelerated by air, light, heat, moisture, and the presence of catalysts such as the metal copper. Oxidative deterioration is autocatalytic.

Since Moureu and Dufraisse³¹ found that hydroquinone had an inhibitory effect on the oxidation of benzaldehyde, a great deal of investigative work has been directed toward discovering chemicals which will inhibit spoilage resulting from the development of rancidity. So many substances have been proposed for this purpose that it is difficult to classify the compounds having this activity. Among them may be mentioned acids, quinones, phenols, amines, etc. Not all the substances which have antioxidant activity and which can be used, for instance, in rubber and cosmetics for this purpose can also be used for foods, because some are definitely known to be toxic.

Among the acids³² may be mentioned the dicarboxylic acids containing an hydroxyl group, such as tartaric acid and citric acid. These have been found to be effective in the preservation of lard and vegetable oils. Maleic acid also has an antioxidant action.

Hydroquinone is representative of the phenols which have been suggested. Among the other phenols which have been used experimentally are catechol, guaiacol (the monomethyl ether of catechol), resorcinol, orcinol, and pyrogallol.³³ Sarcosine, the N-methyl derivative of glycine, and cysteine hydrochloride are among the amines which have been proposed for this purpose.³⁴

Carotene, which has little antioxidant action during the induction period, has considerable antioxidant power after this period, as have other carotenoid pigments.³⁵

Olcott and Emerson³⁶ found that the α -, β -, and γ -tocopherols (see Volume I, page 250) and their allophanates which are obtained in the unsaponifiable fraction of vegetable oils are effective antioxidants in lard and other animal fats. However, the degree of protection afforded was not proportional to their vitamin E activity. They are not effective when reincorporated into vegetable oils. These substances were named inhibitols.³⁷ Olcott and coworkers concluded that the action of antioxidants of known structure depends upon the presence of a free hydroxyl group. Thus it has been shown by Columbic³⁸ that chroman, to which the tocopherols are related

³¹ C. Moureu and C. Dufraisse, *Compt. rend.*, 174, 258 (1922).

³² G. R. Greenbank and G. E. Holm, *Ind. Eng. Chem.*, 26, 243 (1934).

³³ M. R. Coe and J. A. LeClerc, *Oil & Soap*, 12, 231 (1935).

³⁴ L. W. Elder, *Oil & Soap*, 18, 38 (1941).

³⁵ R. C. Newton, *Oil & Soap*, 9, 247 (1932).

³⁶ H. S. Olcott and O. H. Emerson, *J. Am. Chem. Soc.*, 59, 1008 (1937).

³⁷ H. S. Olcott and H. A. Mattil, *J. Am. Chem. Soc.*, 58, 1627 (1936).

³⁸ C. Columbic, *J. Am. Chem. Soc.*, 63, 1142 (1941).

chemically, and coumarin derivatives, which have a hydroxyl group but no side chain, are effective antioxidants. Wheat-germ oil very likely has an antioxidant action because of the tocopherols and the phospholipids it contains.

More complex materials such as vegetable lecithin and other phospholipids derived from soybean oil have also been used. The cephalin fraction of this mixture has been found to have the inhibitory action. Even separate portions of the cephalin molecule have been used and patented for this purpose.³⁹

Some other materials proposed and used (and patented by the Musher Foundation³⁹) are raw oat flour (Avenex), catalase, and many preparations from cereals, grains, milk solids, oils, yeast, animal tissues, legumes, and grasses.

It has been shown through commercial use that gum guaiac³⁹ is a practical and effective antioxidant and stabilizer for lard, oleo oil, chicken fat, dehydrated pork, and possibly other dehydrated fat bearing foods. It has been recommended for the stabilization of paper packaging materials used for fatty foods. The oil absorbed by the liners of the cartons and by the cartons themselves readily turn rancid. By the incorporation of gum guaiac in the paper, this is prevented. Since the gum is not readily soluble in oils and fats it must be incorporated in the fats during the rendering period or by the aid of a solvent in which both the gum guaiac and the fat are soluble. The solvent must subsequently be removed by vaporization. Combinations of some of these substances have much greater stabilizing action than a given substance alone. Thus 0.05% gum guaiac plus 0.002% phosphoric acid has a greater antioxidant action than 0.05% gum guaiac alone. This effect is termed "synergistic action."

It has been pointed out that moisture is a factor in the production and acceleration of rancidity. This is probably one of the reasons for the development of rancidity in emulsions such as mayonnaise, in which the water-fat interface has been increased enormously. Certain antioxidants are of little value in the presence of moisture. Gray and Stone⁴⁰ proposed the use of ascorbic acid and *d*-glucoascorbic acid for antioxidant purposes. The ascorbic acid and *d*-glucoascorbic acid, an analogue of ascorbic acid, are dissolved in the aqueous phase of the emulsion. Such compounds do not alter the taste of the mixture.

Protection from Light.—It may be appropriate to mention at this point, although green light is not a chemical antioxidant, the extensive investigations of Coe⁴¹⁻⁴³ on the use of green filters, green transparent papers and Cellophanes, green glass, etc., as packaging materials for the effective retardation of rancidity. It has been found that oils and fats absorb light in the ultraviolet and blue ends of the spectrum and, to a slighter extent, those at the red end. It is probable that the activity derived from the absorption of these light waves causes the oils and fats to become rancid.

³⁹ H. S. Mitchell and H. C. Black, *Ind. Eng. Chem.*, 35, 50 (1943).

⁴⁰ P. P. Gray and I. Stone, *Food Industries*, 11, 626 (1939).

⁴¹ M. R. Coe, *Cereal Chem.*, 11, 241 (1934).

⁴² M. R. Coe, U. S. Dept. Agr., *Yearbook*, 1934.

⁴³ M. R. Coe, *Oil & Soap*, 14, 171 (1937).

Hence, the exclusion of such wave lengths will retard the formation of rancidity. Not every shade of green is equally effective; the most effective for this purpose are those which are penetrated only by light waves of 4900 to 5800 Å. This shade is approximately that of chlorophyll green or grass green.

2. For Fruits and Vegetables

The browning of fruits and vegetables, particularly when cut, sliced, diced, etc., presents another serious problem. The browning of such fruits as apples, peaches, pears, apricots, etc., in the fresh state is caused by oxidation probably induced by the oxidase in the fruit and possibly because of other factors. These are discussed on page 310. It is a marked disadvantage to have this browning occur during processing.

It has been shown that thiourea⁴⁴ or thiocarbamide, NH_2CSNH_2 , can retard the oxidation which these fruits and vegetables undergo. The cut fruit is dipped for not more than 30 seconds into a dilute aqueous solution of thiourea, containing about 0.05% thiourea, and is then drained. It may be placed in a refrigerator, frozen, or canned, and the browning will be prevented for many months. Even at room temperature the original color will be retained for a day. Apple juice which has darkened in color may be partially restored to its natural color by the use of this chemical. Fruits and vegetables to be dried, cut fruit for salads, sliced potatoes, and fruits for pies have been treated by this process to retard oxidation. Sliced apples dipped into the 0.05% solution contained about 30 p. p. m. of thiourea remaining on the surface of the fruit. Several investigators^{45, 46} have shown that thiourea is not toxic.

Sulfur dioxide⁴⁷ exerts a strong inhibiting action on the darkening by oxidizing the natural color bases of fruits such as apricots, peaches, pears, and apples in addition to bleaching on the anthocyan pigments. The use of sulfur dioxide as an antioxidant was discussed previously. See page 309. An analogous antibrowning agent for apples is a mixture of sodium chloride brine and sodium sulfite solution. Sodium thiosulfate has also been proposed as an antioxidant for cut fruits and vegetables.

Woodroof⁴⁸ describes a method of dipping or rinsing sliced peaches in 2% citric acid solution or 0.1% hydrochloric acid for one minute as a means of preventing browning.

V. NEUTRALIZERS

The use of neutralizers in the neutralization of sour cream for the manufacture of butter is a well-known practice. Actually, the sour cream is not completely neutralized, for the concentration of the acid is reduced by the addition of these substances

⁴⁴ F. E. Denny, *Contrib. Boyce Thompson Inst.*, 7, 55 (1935).

⁴⁵ F. B. Flinn and J. M. Geary, *Contrib. Boyce Thompson Inst.*, 11, 241 (1940).

⁴⁶ Albert Hartzell, *Contrib. Boyce Thompson Inst.*, 11, 249 (1940).

⁴⁷ W. V. Cruess and W. Y. Fong, *Fruit Products J.*, 8, No. 10, 22 (1929).

⁴⁸ J. G. Woodroof, *Food Industries*, 12, No. 5, 35 (1940); 12, No. 6, 50 (1940).

to about 0.1–0.3%. Hunziker⁴⁹ prefers the term "standardization" for this process. The principal object of adding neutralizers is to improve the keeping quality of butter made from cream of high acidity; consequently these substances are used for a preservative action. Additional factors for their use are the avoidance of excessive fat losses during churning and guarding against undesirable flavors.

Lime neutralizers are among the most important in butter manufacture. They are placed into three groups depending upon their magnesium content. Low magnesium limes contain 5% or less of magnesium; medium magnesium limes contain 30–35% magnesium; and high magnesium limes contain from 40–45%.

Among the soda-type neutralizers are sodium bicarbonate, sodium carbonate, sodium sesquicarbonate ($\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O}$), and sodium hydroxide plus sodium carbonate. Combinations of neutralizers are generally used, in order to avoid an undesirable effect on the taste of the butter produced.

The use of neutralizers for the standardization of fluid milk and cream is not looked upon with favor. The object of the addition of these substances to fluid milk and cream is to prevent the acidity from rising high enough to curdle the milk or the cream. In establishing the definitions and standards of identity for evaporated milk (see Volume I, page 424), the Food and Drug Administration banned the use of sodium bicarbonate because it noted that, while this substance could be used for stabilizing milk, it might also be added for the purpose of neutralizing sourness to permit the use of unfit milk. In order to overcome the production of lumpy, grainy, or excessively thick evaporated milk, the addition of disodium phosphate, sodium citrate, or both, or calcium chloride not exceeding 0.1% by weight of the finished evaporated milk, is permitted.

The use of lime in the neutralization of sugar-cane juice and sugar-beet extract for clarification purposes is discussed on pages 540 *et seq.*

The use of sodium or potassium bicarbonate, carbonate, or hydroxide, of magnesium carbonate or oxide, or of any combination of these substances is a method of long standing in the processing of chocolate and breakfast cocoa. The products are generally known as alkalized chocolate or cocoa.

Calcium "lactophosphate," which is a mixture of calcium lactate, calcium acid lactate, and calcium biphosphate (calcium superphosphate), has been proposed as a neutralizer in milk products. Sodium alginate, sodium caseinate, the pectates of strong bases and, in general, salts of weak acids and strong bases have the ability to function as neutralizers in food products.

Salt Balance Adjusters and Cation Exchange

It has been shown by Willstätter that the natural green pigment of all higher plants is a mixture of chlorophyll *a*, $\text{C}_{55}\text{H}_{72}\text{O}_5\text{N}_4\text{Mg}$, and chlorophyll *b*, $\text{C}_{55}\text{H}_{70}\text{O}_6\text{N}_4\text{Mg}$. The magnesium constituent of the chlorophylls is nonionic and therefore is carried with the pigment into nonpolar solvents. Willstätter also showed that the retention

⁴⁹ O. F. Hunziker, *Butter Industry*. 5th ed., La Grange, Ill., 1940.

of greenness by chlorophyll and its derivatives is directly related to the retention of pigment magnesium.

It is common knowledge that conventional canning procedures are conducive to the change of color of green vegetables from the natural chlorophyll green to a shade termed "olive." Blair and Ayres⁵⁰ state that the primary step in the degradation of chlorophyll in canning is the loss of pigment magnesium in the hydrolytic conversion of chlorophyll to pheophytin:



While it is possible that chlorophyll may be protected against acidic plant saps by protein-pigment compound formation, or possibly by physical segregation in the chloroplasts of plant tissue, such means are unavailable technologically, for these factors are destroyed in the cooking process. The establishment of an alkaline environment is the means most commonly available for the preservation of the natural green color of vegetables. A factor to be considered is that an alkaline environment may inactivate some vitamins.

One of the earliest methods for the production of an alkaline environment in canning was that of Blassneck. In his method, the vegetable was either soaked at room temperature in a suspension of calcium hydroxide or blanched at a higher temperature in the same suspension. Another method was based on the use of an alkaline buffer solution depending upon disodium hydrogen phosphate or sodium carbonate or magnesium hydroxide. Still another investigator recommended magnesium carbonate, which was stated to be mild enough in its action to neutralize the organic acids of the vegetable without attacking the tissues. Adam⁵¹ increased the pH to preserve peas by use of 1.5% sodium carbonate or 8% sodium phosphate, but found that undesirable alkaline flavors were produced.

Blair and Ayres⁵⁰ developed a method for the protection of the natural green pigment in the canning of peas in which it was possible to retain approximately 60% of the pigment magnesium. This method depends on three major steps: (1) a pre-treatment, involving the immersion of the peas at room temperature in 2% (0.19 M) sodium carbonate solution for 30 to 60 minutes; (2) blanching in a 0.005 M calcium hydroxide solution; and (3) processing the peas in a salt-sugar brine which is also a 0.020-0.025 M suspension of magnesium hydroxide. This procedure protects unaltered chlorophyll against hydrolytic decomposition by the elevated *pH* of the environment. The *pH* is brought to about 8 in the first step and is maintained at that value through blanching and sterilization by the use of alkaline reagents in each step. The texture of the peas in the median *pH* range is not controlled by the *pH* level but by the cationic equilibria existing between the peas and the solutions with which they are treated in the canning process. Thus, the calcium and magnesium contents of peas are markedly decreased by base exchange with a cold solution of

⁵⁰ J. S. Blair and T. B. Ayres, *Ind. Eng. Chem.*, 35, 85 (1943).

⁵¹ W. B. Adam, *Food Tech.*, 1, 343 (1932).

sodium chloride, but little affected by extraction with cold water. The use of hydroxides of calcium and magnesium in small concentration in the later steps of the canning process prevents the softening attributed to the use of alkaline agents such as sodium carbonate and sodium phosphate.

Another example of the use of cation exchange in food products is that of the production of soft-curd milk. This has been discussed previously (see Volume I, page 417).

VI. STABILIZERS

Stabilizers are used in various branches of the food industry to prevent the occurrence of undesirable changes, and therefore may be grouped with chemical preservatives. In some cases they are unnecessary; in other instances they may be considered optional ingredients; and in still others they are practically indispensable for the production of an adequate product.

As Cole⁵² points out, since the nature of the food products requiring stabilization varies considerably, it may be necessary not only to select the proper agent but also to regulate the method of processing in order to secure the desired result. In some cases it is necessary to add the stabilizing agent to the food product; in others it may merely be necessary to inhibit or inactivate the enzyme which might degrade a food component capable of acting as a stabilizer. Even though the physical properties of a product can be stabilized by any one of several agents, it is best to make a proper selection in order to avoid undesirable chemical changes. Metallic colloidal precipitates may be prevented by adding agents which avert the chemical changes responsible for the precipitate.

1. Classification

Stabilizers may be classified into six groups. Those that stabilize (1) emulsions, (2) the texture of frozen products such as ice cream and analogous frozen desserts, (3) process cheese, (4) suspensions, (5) jellies, and (6) foams.

In the first group may be placed those substances which concentrate in the interface in oil-in-water emulsions. Such an agent lowers the interfacial tension of the food products, generally in a three-component system, and thus increases the stability of the system. This principle is used in the manufacture of mayonnaise and has been discussed in other sections of this text. See Volume I, pages 42 and 901. Fresh egg yolk, lecithin, phospholipids, gelatin, and vegetable gums are examples of this class of stabilizers.

In ice cream and analogous frozen desserts, small ice crystals tend to disappear and large crystals tend to grow larger as a result of the alternate melting and freezing to which the ice cream is subjected because of fluctuations of temperature during storage and transportation. In order to assist in the production and maintenance of an even texture, to prevent shrinkage, and to assist in the incorporation of air, stabilizers are

⁵² W. C. Cole, *Food Industries*, 13, No. 9, 44 (1941); 13, No. 10, 57 (1941).

almost universally used in the manufacture of ice cream. Gelatin is probably the most common agent used, but sodium alginate is also extensively employed. Because agitation affects the action of certain stabilizers, their usefulness in home refrigerator ice cream is not the same as in commercial products.⁵³ Agar in combination with dried skim milk powder is better than egg yolk, Indian gum, pectin, and gelatin. Agar or gelatin combined with mayonnaise are satisfactory for fruit salads. Eggs are the required stabilizer for custard and French-type ice cream.

In the manufacture of process cheese, which in 1943 comprised from 40–50% of all cheese produced, stabilizers are added to assist in the production of an homogeneous mass with the desired texture. These agents are also termed emulsifiers or plasticizers. The agents most commonly used, such as sodium citrate, potassium tartrate, disodium phosphate, and sodium caseinate, are alkaline in reaction. However, since the production of a proper pH is one of the requirements of a good product, it may at times be permissible to add ortho, meta, and poly acid phosphates, dibasic citric acid, or citric acid itself. They are generally used on the basis of 1 or 2% by weight of the bulk cheese used.⁵⁴ Calcium lactate is considered to be a better plasticizer than either sodium or potassium lactate.

The stabilization of suspensions by preventing or retarding the precipitation of materials in suspension is another function of stabilizers. The stabilization of fruit and vegetable juices may be taken as representative of this group. These food products contain pectins which can act as stabilizers and retard the settling of the fruit and vegetable particles. However, in many instances the food product also contains an enzyme which may destroy this power. Thus, in the case of tomato juice a pectase, pectin methoxylase, is present which splits off methyl alcohol leaving pectic acid, which does not have the colloidal properties of pectin. Kertesz⁵⁵ showed that this enzyme can be inactivated by heating the juice to 176° F. for 45 seconds. Additional stability can be given tomato juice by homogenization. Grapefruit juice and orange juice also contain naturally occurring pectins that are capable of stabilizing the colloidally dispersed solids of the juice.

While chocolate and chocolate milk drinks contain naturally occurring substances, derived from the cocoa ingredient, which assist in the retardation of fat separation and the settling of solids, it is customary to add materials such as tapioca flour and sodium alginate to assist in the stabilization.

Although in the manufacture of jams, jellies, and preserves, pectin is a necessary component, it is also necessary to have a proper concentration of acid and sugar to produce an adequate product. Some fruits, like apples, provide sufficient pectin of their own. For those which are deficient in pectin, it is necessary to add this stabilizing agent. See page 614.

Foams, as well as emulsions, may be considered as three-component systems in which a gas is the dispersed phase. Surface-active substances such as long-chain

⁵³ L. S. Bentley and B. M. Watts, *Food Research*, **4**, 101 (1939).

⁵⁴ C. R. Barker, *Food Industries*, **13**, No. 12, 53 (1941).

⁵⁵ Z. I. Kertesz, *Food Research*, **4**, 113 (1939).

organic acids and their salts, sugars, alcohols, and esters readily form foams. It is generally necessary to have a stabilizing agent present to increase the stability of a foam. Saponins, natural and added, act as foam stabilizers.

Among the food products in which foams are stabilized are whipped cream, baked goods, and candy. In beer and analogous alcoholic beverages and in certain non-alcoholic beverages such as root beer, the stabilization of foam is important. Aerated products such as ice cream, whipped butter, and aerated chocolate can also be considered in this category.

Cream with a fat content of over 30% contains components which assist in the formation of a relatively stable foam when air is incorporated by agitation, but the stability and volume of foam produced can be greatly increased by the use of nitrous oxide. In whipped butter and in aerated chocolate, naturally occurring ingredients serve to entrap the air. In the manufacture of ice cream, the increase of volume as a result of the incorporation of air is an important factor in its sale, since ice cream is sold by volume. In bakery goods, eggs are a principal foam stabilizer; and in confectionery, gelatin and pectin are used.

2. Other Uses

Stabilizers may be used for other purposes than preservation of the form in which a food product is produced. Some of the stabilizers mentioned can also serve as neutralizers. Thus, materials such as sodium caseinate, sodium alginate, disodium phosphate, and other compounds which are the product of a strong base and a weak acid progressively hydrolyze with the production of alkali. The alkali produced may be used by the food product for the neutralization of acid formed by the decomposition of the product.

Many of this group of agents are also termed thickening agents when used primarily to obtain a thickening effect. Gelatin, starch, dextrin, the vegetable gums (see Volume I, page 819)—such as arabic, ghatti, Irish moss, tragacanth, agar, Indian gum, locust kernel, salep, quince seed mucilage, and pectin—have been used for this purpose. Calcium sucrate or sucrate of lime was used as a cream thickener. The methyl and ethyl ethers of cellulose and other cellulose derivatives have been proposed as stabilizers and thickening agents for food products. There has been some use made of these agents (Tylose SL 400, Tylose S 400, Fondin) in Germany.⁵⁶

VII. FIRMING AGENTS

Fresh tomatoes, like all fresh fruits, contain pectic components which are relatively insoluble and which form a firm gel around the fibrous tissues of the tomato, thus preventing the collapse of the vegetable and in that way aiding in keeping it firm. When there is a breakdown of the cell structure, the pectic components are brought into contact with the enzymes of the food, and the pectin is converted into pectic acid. This imparts less firmness to the tomato tissues than the original pectin, in turn

⁵⁶ E. Letziger, *Z. Untersuch. Lebensm.*, 84, 289 (1942).

causing collapse. The addition of calcium salts to tomatoes causes the formation of a calcium pectate gel which supports the tissues and protects the tomato against softening. The only salt demonstrated to be entirely satisfactory is pure, anhydrous calcium chloride.⁵⁷ Hence purified calcium chloride may be added to tomatoes in a quantity reasonably necessary to firm the tomatoes but in no case to exceed 0.07%, calculated as anhydrous calcium chloride, of the weight of the finished canned product. Excessive amounts of calcium chloride give the tomatoes a salty or bitter taste and render the fruit tough or rubbery in texture.

Firming agents have a definite effect on the ease of penetration of sulfur dioxide into fruit. Thus Woodroof and Cecil⁵⁸ found that the resistance was least with calcium sulfate, followed by calcium monophosphate (calcium superphosphate, $\text{Ca}(\text{H}_2\text{PO}_4)_2$), calcium chloride, lime, and calcium carbonate.

With strawberries, calcium carbonate was the most effective firming agent, while calcium monophosphate was next most effective. The other calcium salts showed little difference in their firming power. With Young dewberries, calcium chloride was the most effective firming agent; calcium carbonate was next best; and there was little difference in the effect of the others.

Alum, potassium aluminum sulfate, is sometimes used as a firming agent in the processing of pickles. Soft pickles are rendered somewhat firmer by the use of this agent but an undesirable property is added because alum acts as an astringent and gives pickles treated in this manner a tart taste.

VIII. COATINGS AND WRAPPINGS

Coatings and wrappings are applied for two principal purposes—first, to prevent the entrance of microorganisms, and second, to prevent the loss or access of water. Other aims are, at times, achieved. The use of green transparent wrappings for the prevention and retardation of rancidity in oils and oil bearing foods was mentioned on page 411.

Under the combined term of coatings and wrappings, we may include the use of tin foil, aluminum foil, Pliofilm, latex, synthetic plastics and resins, cellulose film, cloth coverings, paraffin, waxes, cold-wax emulsions and films of chemicals left after dipping into aqueous solutions of borax, hypochlorite, and other antiseptics. The topic of proper packaging will be discussed. See page 425. The subject of the protection of food against chemical warfare agents by the use of wrappings has been discussed by Jacobs.^{59, 60}

Many foodstuffs, like fruits, vegetables, cheese, and meats, are fairly well protected. Once undesirable organisms enter, however, spoilage proceeds rapidly. In order to avoid this type of spoilage and the type of degradation resulting from the

⁵⁷ *Federal Register*, 1940, p. 1825.

⁵⁸ J. G. Woodroof and S. R. Cecil, *Fruit Products J.*, 22, 132 (1943).

⁵⁹ M. B. Jacobs, *J. Chem. Education*, 20, 282 (1943).

⁶⁰ M. B. Jacobs, *War Gases*. Interscience, New York, 1942.

loss of moisture, it is customary to apply coatings and wrappings as additional protection.

Illustrative of the former is the coating of apples with sodium tetraborate or borax as a mold preventative. Oranges are sometimes coated with borax for protection against molds, and in addition are waxed and polished to prevent loss of moisture. An analogous practice is the preservation of eggs and meat by dipping them into hot oil: The oil closes the pores in the eggshells and seals the cells of the meat; the impervious layer formed prevents the loss of water from both the eggs and the meat and retards the entrance of microorganisms. Glue, gelatin, melted fat, and shellac are also used for different foods.

Rideal mentions that eggs can be preserved for months by keeping them in a pan of lime water, or by dipping them in a cream of slaked lime and water. The shell is made impervious by the production of a coating of calcium carbonate. In addition the albuminous inner lining of the shell is coagulated.

A patent has been granted for a jellylike coating for meat which does not support mold growth, is toxic to bacteria, and is impervious to air. It consists of a combination of an acid such as lactic, tartaric, citric or malic; a metallic pectinate, preferably of nickel or cobalt; and a sugar or a polyhydroxy alcohol such as glycerol and water. The metallic pectinate should contain from 0.2–1.0% nickel or cobalt. These pectinates are said to be harmless if taken internally because of their colloidal character and stability.

Glyceryl monostearate has been suggested as a protective coating for edible hygroscopic powders, crystals, and tablets which absorb moisture from the air and subsequently tend to lump, cake, or decompose. A solution of this substance in hot alcohol or other suitable solvent is sprayed on the powder which can be tumbled in a heated cylinder until all of the solvent has evaporated. This leaves the product coated with a thin, protective film of the monostearate which disperses when the product is dissolved or placed in water.

1. Waxing

It has long been known to plant physiologists, as pointed out by Platenius,⁶¹ that a thin film of natural or artificial wax on the surface of plant tissue is effective in reducing its rate of water loss and consequently reduces wilting. Actually, even excessive water loss from some vegetables will not affect their edibility, but the wilting they undergo renders them less attractive to both buyer and consumer. The principal value of all waxing operations is the reduction of shrinkage losses and rate of wilting, as well as a decrease in the rate of transpiration. Waxing does not really prevent the growth of bacteria and fungi already present unless antiseptics are incorporated in the coating.

The use of wax coatings for the preservation of fruits and vegetables has increased during the past two decades. Over 75% of all oranges grown in California and

⁶¹ H. Platenius, Cornell Univ. Agr. Expt. Sta., *Bull. 723* (1939).

Florida are treated by one of the methods described below or some analogous process. Other foodstuffs waxed successfully on a commercial scale are apples, cantaloupes, cucumbers, tomatoes, peppers, and eggplants. Platenius advocates the extension of cold waxing, to many other vegetables. There are four principal methods of waxing vegetables and fruits.

(a) *Liquid Paraffin Method*

Vegetables or fruits are dipped into hot liquid paraffin to which, at times, other substances such as resins are added. When used for rutabagas, this method is known as the "Canadian process." Its chief advantage lies in the fact that it provides a more complete coating. Its disadvantage is that much coating material must be used.

(b) *Slab Wax Method*

A slab of paraffin or other type of wax is pressed against rapidly revolving brushes which transfer the wax to the fruits being coated. This method is not very efficient.

(c) *Spray Method*

The Brogdex variation, used principally for citrus fruits, consists of spraying a mixture of melted wax on the fruit, which is subsequently brushed mechanically until a film of the desired thickness and gloss is obtained. In another variation, the wax is dissolved in a suitable solvent. This mixture is subsequently atomized, the resultant fog being permitted to impinge on the fruit. Both spraying methods require elaborate equipment and are inadequate for vegetables because of the high temperatures involved.

(d) *Dipping or Cold Wax Process*

The vegetables and fruits are first washed and then, without being dried, are dipped into a wax emulsion of the proper concentration. After removal from the waxing tank, the fruits and vegetables are permitted to dry thoroughly before being packed for shipment. This method is probably the most simple of those mentioned.

Essentially, all cold wax emulsions are colloidal suspensions of one or more types of wax in water, in which the wax is maintained as the dispersed phase by means of a soap made from oleic or linoleic acid and ammonia, sodium hydroxide, potassium hydroxide, or more usually, triethanolamine. The wax is generally carnauba or paraffin to which mineral oil, shellac, or resins have been added. One of the ingredients of Dowax is bentonite.

2. Impregnated Wrappers

The use of wrappers impregnated with antiseptic substances for the packaging of foodstuffs is by no means a recent development. More than fifty years ago, paper coated with a mixture prepared from 5 parts of paraffin wax, 5 parts of stearin, and

2 parts of phenol was used in Europe for wrapping meats. Cheese wrappers were prepared from closely woven canvas soaked in boric acid and boroglyceride. In more recent times, chemically treated papers have been used for the wrapping of apples, pears, oranges, and similar fruit. Paper impregnated with formaldehyde has been used for the wrapping of butter.

Wrappers impregnated with sodium propionate and calcium propionate have been used to prevent mold growth on butter,⁶² but this practice has not found widespread favor because it gives the butter a pronounced propionate odor.

The use of chemically treated artificial and natural sausage casings is another illustration of the prevention of spoilage by the use of treated wrappers. Wrappers containing 0.44% of the weight of the paper of *o*-phenylphenol⁶³ were effective in protecting oranges and lemons against certain microorganisms. More than 9 mg. of the agent per square foot of paper injured the rind, but impregnating the paper with a fatty oil such as peanut or olive permitted higher concentrations of the antiseptic to be used. An analogous type of wrapper is one impregnated with organic mercury compounds.

A variation of the coatings mentioned above are those employed for asphalt-coated ham or bacon. The salted and smoked meats are generally prepared for export to tropical countries by being wrapped heavily in several thicknesses of paper and then being dipped into asphalt.

3. Mycostatic Vapors

Mallman and Michael,⁶⁴ in a study of methods for the prevention of mold growth on cold storage eggs, used two types of mycostatic agents. In the first group were compounds, such as borax, boric acid, sodium benzoate, and various cupric compounds, which had little or no vapor pressure and exerted their preservative action by direct contact. In the second group were organic compounds, such as sodium *o*-phenylphenate (Dowicide A), sodium 2-chloro-*o*-phenylphenate (Dowicide C), sodium 2,4,5-trichlorophenate (Dowicide B), sodium 2,4,5,6-tetrachlorophenate (Dowicide F), and sodium pentachlorophenate (Dowicide G), which had sufficient vapor pressure to give off, slowly and continuously, a vapor with marked mycostatic action. The direct contact group was not as good for mold prevention as the group giving off mycostatic vapors. Sodium 2,4,5-trichlorophenate proved to be best in laboratory experiments but sodium pentachlorophenate (Dowicide G) proved best on a commercial scale. When introduced into fillers and flats in concentrations of 0.4% or greater it suppressed all mold growth in both packages and eggs.

IX. EXPANDED USE OF CHEMICALS

This chapter has shown that the use of chemicals in food processing has expanded tremendously in recent years. Many of these chemicals are permitted as optional

⁶² H. Macy and J. C. Olson, *J. Dairy Sci.*, **22**, 527 (1939).

⁶³ J. E. van der Plank, J. M. Rattray, and F. G. van Wyk, *J. Pomology Hort. Sci.*, **18**, 135 (1940).

⁶⁴ W. L. Mallman and C. E. Michael, Michigan Agr. Expt. Sta., *Tech. Bull.* **174** (1940).

ingredients in the standards of identity set up by the Food and Drug Administration. While some are termed neutralizers and others are called stabilizers, plasticizers, emulsifiers, thickening agents, and firming agents, in a larger sense, as explained previously, they are all chemical preservatives because one of their principal functions is to retard or mask undesirable changes in foodstuffs. Some of these substances have no bacteriostatic or fungistatic action, but do hinder the development of spoilage which is a result of other types of action than those of microorganisms.

In discussing the expanded use of chemicals, it is also proper to consider the use of tenderizing agents or proteolytic agents. One of these, bromelin, a proteolytic enzyme occurring in pineapple juice,⁶⁵ has been used to tenderize the animal casings of sausages. Kilmer⁶⁶ early noted the use of another enzyme, papain, from papaya, by natives of Central and South America for the purpose of tenderizing meat.

It may be useful to mention some of the chemicals used routinely in the manufacture of food products.

In breadmaking, in addition to the yeast nutrients, improvers, baking powders, and flour bleaches, the following compounds may be employed: calcium sulfate, calcium lactate, ammonium phosphate, ammonium sulfate, ammonium chloride, ammonium carbonate, and ammonium lactate, or any combination of these not exceeding 0.25 part per 100 parts by weight. The use of baking powders, yeast nutrients, etc., has been previously discussed. See Volume I, page 691.

A large number of phosphates are in common use. Tribasic calcium phosphate, $\text{Ca}_3(\text{PO}_4)_2$, is used as an antacid and as a conditioner to prevent the caking of sugar, salt, and other powdered materials. Disodium dihydrogen pyrophosphate (acid sodium pyrophosphate, $\text{Na}_2\text{H}_2\text{P}_2\text{O}_7$) is used as a leavening agent. Disodium phosphate, Na_2HPO_4 , and sodium hexametaphosphate, $(\text{NaPO}_3)_6$, are used extensively as emulsifiers in the preparation of process cheese. Disodium phosphate is also used in the adjustment of the acidity of condensed milk. Trisodium phosphate is used to remove insecticide spray from fruits and vegetables and to inhibit the growth of fruit mold. Calcium "lactophosphate," as mentioned previously on page 413, has been suggested as a neutralizer in milk products.

The monoglycerides and diglycerides of fat forming fatty acids may be used in oleomargarine in amounts not exceeding 0.5% of the weight of the finished product. These substances may also be used with sodium sulfoacetate derivatives to aid in emulsification, to reduce moisture leakage, and to improve the texture and pan-frying quality of oleomargarines.

X. GAS STORAGE

The preservation of fruits and vegetables by storage in artificial atmospheres is based on the principle⁶⁷ that lowering oxygen content and increasing carbon dioxide

⁶⁵ J. M. Ramsbottom and C. A. Rinehart, *Food Industries*, 12, No. 6, 45 (1940).

⁶⁶ F. B. Kilmer, *Am. J. Pharm.*, 73, 272 (1901).

⁶⁷ H. H. Plagge, *Food Industries*, 12, No. 10, 46 (1940).

concentration decreases respiration and delays the ripening of stored products. One of the simplest methods of controlling such atmospheres is to make the storage room airtight and permit sufficient fresh air to enter to maintain a known carbon dioxide-oxygen ratio. This type of control is possible because, in respiration, fruits and vegetables give off carbon dioxide and consume oxygen. Ventilation with fresh air is satisfactory if the sum of the concentrations of oxygen and carbon dioxide is equivalent to the concentration of oxygen in normal air. If other concentrations are to be used, it is necessary to restrict the amount of fresh air which can enter and to remove excess carbon dioxide by absorption with caustic soda. It is generally possible to store food products at relatively higher temperatures if gas storage is used. The chief disadvantage of gas storage is the difficulty in constructing airtight buildings.

Carbon dioxide has been used for the preservation of eggs.⁶⁸ The eggs are sorted, weighed, and arranged in waxed cartons of 100 eggs each. These are placed in wooden crates into a tank which can be hermetically sealed. The air is evacuated until a vacuum of about 10 mm. Hg is obtained. Then carbon dioxide is pumped in until the pressure is somewhat greater than atmospheric. The temperature can be held at 32-34° F.

Inert gases such as nitrogen and carbon dioxide have been used to provide inert atmospheres in canned evaporated milk and for canned cheddar cheese. Under the terms of the Food, Drug, and Cosmetic Act, it is not necessary to declare the presence of inert gases used in the canning of fruits and vegetables even though they do have additional preservative action. The storage of dehydrated foods in inert atmospheres is a means of reducing loss of palatability.

XI. GAS MATURATION

Some 50 years ago it was known that, when kerosene was used as the fuel for the prevention of freezing of fruits in transport, speedier ripening of the fruit resulted. The cause of the ability of the heat method to ripen citrus fruits was first traced to the incomplete combustion of the kerosene, and finally to one of the products of that incomplete combustion, namely, ethylene. This gas does not add color to the fruit or vegetable which is ripened but hastens the destruction of the chlorophyll masking the natural ripe color of the foodstuff. Ethylene is also a natural product of the respiration of most plant tissue,⁶⁹ thus accounting for the accelerating effect that ripening fruit has on unripened fruit. Ethylene will assist in coloring almost every kind of green-colored vegetable or fruit. The use of ethylene for the artificial coloring of immature foodstuffs is illegal; it may be used only for mature fruits and vegetables. Tomatoes, bananas, and citrus fruits are the products most commonly ripened by the use of ethylene, although melons, apples, pears, pineapple, and tropical fruits are also artificially colored with this agent. Celery is commonly blanched by the use of ethylene.

⁶⁸ W. Rudolph, *Chem.-Ztg.*, 62, 641 (1938).

⁶⁹ N. C. Thornton, *Food Industries*, 12, No. 7, 48; 12, No. 8, 51 (1940).

The usual concentration is generally 1 part of gas to 1000 parts of air. However, 1 cu. ft. of the gas in 20,000 cu. ft. of air has been found effective for some products. Since more than 1 cu. ft. per 1000 cu. ft. of air will not speed up the maturation, greater concentrations of ethylene are merely wasted.

An atmosphere containing 1% of acetylene at 21° C. has been used successfully in hastening the ripening of tomatoes, citrus fruits, peaches, plums, and other fruits.

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Chapter XIV

PACKAGING

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I. THE FUNCTIONS OF PACKAGING

Only when his attention is forced in that direction does the average person realize how extensively and rapidly packaging has grown to occupy an indispensable place in our economy. Indeed, most people think of packaging in terms of external decoration and glamour, apparently unaware of its utility. But packaging goes much farther than mere externals and performs important functions which today most consumers take for granted.

1. Protection

Foremost of these is the protective function. The journey from prime producer to ultimate consumer is often long, sometimes halfway around the globe, and the waits at the distribution way stations vary from days even to years, and are of unpredictable duration. But the product must reach the consumer in usable condition, with its freshness of flavor and its attractiveness of appearance unimpaired. Throughout the journey, the package must protect the product from thermal changes, from humidity variations, and from the hazards of rough handling. The package must often endure long periods of storage; it must repel rodents and infestation; and inner containers, in actual contact with foods, must be odorless, tasteless, and nontoxic.

A package meeting all these requirements is extremely rare. Some package engineers declare that the perfect package is yet to be developed; but all agree on the need for a high standard of testing package materials to determine such characteristics as:

1. Mechanical properties: tensile strength; percentage of elongation; bursting strength; tearing strength; and folding endurance.
2. Physicochemical properties: water absorption; moisture vapor permeability; permeability to gases; resistance to acids; resistance to alkalies; resistance to greases and oils; and resistance to organic solvents.
3. Permanency properties: resistance to temperature variations (maximum and minimum); resistance to sunlight; resistance to storage; and flammability.

There probably is no one packaging material which can successfully meet all those

requirements. As will be seen later, the complete package is often made up of several materials, each of which performs its own part in the protective function.

There are a number of independent research and testing laboratories in various parts of the United States where a packer may obtain tests on either package materials or finished packages. Standardized tests have been developed by such organizations as the American Society for Testing Materials, Philadelphia; the Technical Association of the Pulp and Paper Industry, New York; the American Standards Association, New York; and the Bureau of Standards, Department of Commerce, Washington, D. C.

2. Convenience

Less technical, but of equal importance, is the fact that a product must be packaged so that it affords convenience throughout its existence. Particularly is this true in the food field. Beginning in the producer's plant, even before the product is packed, the packaging material must be capable of being stored and handled conveniently. On the production line, there can be no slowing up because of awkward or unusual types of packages. Cartons must be scored and glued so that the machines can maintain production rates without delays. Tin cans and glass containers must be adapted to mass production. Labels and closures must lend themselves to routine machine operations.

A different set of conditions is encountered in the wholesale and retail channels of distribution, where convenience is no less desirable. Cases must be of convenient size and weight for storage and shipment to retailers, and, if sales of broken case lots are made, the part that is sent out and the part left in storage must both be in convenient condition. For the retailer, provision must be made for convenient stacking on shelves, in bins, or on counters, with considerable thought given to convenience in display and dispensing of merchandise.

Consumer convenience, too, must be planned for. Packages must be of the right size for refrigerator, kitchen cabinet, or pantry shelves. Closures of glass containers, tight enough to be tamperproof and leakproof before reaching the home, should not require derricks or sledge hammers to remove, and, if the product is one which is consumed over a considerable period, should be conveniently constructed for reclosure. Then, too, consumers appreciate devices like pouring spouts, dispensers, and transparent "windows," partly for identifying the product and partly for keeping track of the amount on hand.

3. Economy

Packaging would never have developed to its present extent if it had not made a contribution to economy. In some of the luxury lines, the consumer is agreeable to paying an extra trifle—sometimes more than a trifle—for a fancy package, purely for esthetic reasons. In the food field, however, margins are small and competition is keen. Differences of fractional pennies in cost are sufficient to attract or repel consumer favor, or to cause consumers to seek a substitute. Consequently, the food producer watches his packaging costs with an eagle eye.

From a broader point of view, although there has been a notable lack of scientific study on the subject, it can probably be established that packaging in the food field goes considerably farther than merely paying its own costs. Butter is often cited as an example. It is only necessary to recall the bulk packaging of butter from the tub to appreciate the superiority of the modern method. In the old days, a clerk with hands none too clean measured out what he thought was a pound into a wooden butter boat, put a sheet of vegetable parchment over it, wrapped the package in kraft paper and tied it with a string. If in the process some went overboard onto the floor or into the bottom of the icebox, it was retrieved—if no customer was looking—because there was always considerable spoilage or shrinkage anyway and the retailer had to pass those losses on to the consumer. Today, butter is cut into pound prints, wrapped in vegetable parchment, and put into the producer's branded carton by machine without any danger of contamination from human hands. The actual cost of package and operation is probably less than for the old method, not to mention the improvement in sanitation and the avoidance of spoilage, as well as uniformity of weight and reliability of product under a responsible producer's label. Whether or not it could be demonstrated that all packaged products in the food field are more economical in cost *because* they are packaged is open to question; the fact remains that consumers generally are fully convinced of the values of packaging and are willing to pay a reasonable amount for them.

4. Appeal

The fourth function of packaging is a merchandising one, with advantages both to consumer and producer. Package surface often lends itself to attractive and unmistakable presentation of identity features such as product name, brand name, trade-mark, and identity of the producer or distributor. These features are important to the consumer who has become accustomed to the characteristics or quality of a certain brand, and equally important to the producer who is at considerable pains to maintain consumer favor by maintaining his quality standards.

Statutory provisions and common law have long recognized the property rights inherent in brand names. The United States Patent Office provides for the registration of the brand names and trade-marks used by manufacturers to identify their products; and the user may defend in the courts his right to the exclusive use of them. This right, in the United States, is based on priority of use, and not on registration. In some of the foreign countries, notably those of South America, the reverse is true—a condition which firms doing business abroad should investigate thoroughly. Many of the several States also have trade-mark registration statutes, some of which, it must be admitted, were adopted partly with a view to revenue potentialities and partly to "protect home industries."

A new trade-mark law, known as the Lanham Bill, was placed before Congress in 1943 for adoption; the purport of the bill is to strengthen private property rights in brand names and trade-marks, and also to modernize and amplify registration procedure.

No attempt can be made to discuss the full details of trade-mark registration, particularly in view of pending changes. However, two safe generalizations may be offered:

1. Never adopt a brand name or a trade-mark without first making sure it is available—that is, that it is not currently in use. This may involve a patent search of the records in Washington.

2. Matters of brand registration and trade-mark protection should be placed in the hands of a qualified patent attorney. His fees, properly chargeable to initial promotion expense, may prevent headaches and expensive litigation in the future.

A common practice, to establish the actual use of a brand name for the record, is to make a shipment of the goods for resale into every State in the Union. This fixes the date of adoption beyond doubt.

But in the interests of consumer protection, the exterior of the package has a more important function to perform, and this has been made the subject of strict legislation both by federal laws and by State action. Up to 1906, there was little legal safeguard for the consumer; in that year, as a result of a long discussion, the law known as the Wiley Act was adopted to regulate the packaging of food and drugs. This law remained in force until superseded by the Food, Drug, and Cosmetic Act of 1938, which is without doubt the broadest and most drastic of all laws relating to packaging. Efforts were made by some of the original proponents of the bill as it was first framed to include grade labeling as a requirement, but the law was enacted without this provision. Purely as a measure of price control, the Office of Price Administration has advocated compulsory grade labeling for the duration of the war.

The principal features of the act, insofar as they apply to food packaging, may be summarized as follows:

1. No product may be labeled in a manner that is false or misleading in any particular.
2. The name of the product must appear, and it must be "the common or usual name." Standards of identity and "reasonable definitions" for various products have since been fixed for many food products by the Food and Drug Administration. See page 156.
3. The name and place of business of the producer or distributor must appear on "two or more panels."
4. If a food contains two or more ingredients and is offered under a name for which no standard has been established, each ingredient must be named on the label under its common or usual name.
5. An accurate statement of the quantity of the contents in terms of weight, measure, or numerical count must appear on the package.
6. A food is deemed to be misbranded if its container is so made, formed, or filled as to be misleading.
7. The required statements must be in such terms and of such a size that they will be read and understood by the average person; and nothing in the package design must be allowed to interfere with that purpose.

In adopting this law, Congress took care not to hamper the privilege of the producer to promote his product, via the package, in every legitimate way. With full recognition of the benefits of competition, the lawmakers left the door open, placing no restrictions on the use of design elements that give a package its individuality, pro-

vided only that such elements are not misleading or do not interfere with the legibility of the required information.

Thus a manufacturer is free to make his package as attractive as he can. If he wishes, he may use variety of colors or beauty of design to invite the consumer to buy. He may feature his brand name or trade-mark; he may use an illustration, if truthful, of the product itself; he may present information, pictorially and/or verbally, relating to the origin of the product and ways in which to serve it. Many producers are doing these things, and experience shows that consumers react favorably.

II. PACKAGE DESIGN

The effectiveness of a package design in creating favorable consumer response depends, in part at least, on the manner in which various elements are treated. A design in good taste, with harmonious colors, attracts consumers' eyes, even though there may be no conscious appreciation of design as such. The growth of self-service stores, where consumers make their own selections, places more responsibility than ever on package design. Many a first sale is made by a good-looking package, and—provided the product is reasonably satisfactory in quality—repeat sales follow more easily because of the recognition value of a good design. To expect a good package permanently to compensate for a less desirable product, however, is to place much too great a burden on package design. There is no substitute for product quality. That quality, uniformly maintained, is the *sine qua non* in building consumer brand preference. Good package design is the setting for that jewel.

1. Originating a Design

Many package designs have just grown—and they look it! The most successful ones, however, are the product of an intelligent combination of esthetics and merchandising, for which credit should be given to the art departments of package fabricators, to independent designers, and to package designers in advertising agencies. Some of the larger companies in the food field have departments of package development which work out problems of structure and materials from a functional point of view as well as those of external appearance from the standpoint of merchandising and consumer appeal.

In originating a package design, it is well to approach the subject from the merchandising angle. Though the list that follows is by no means complete, answers to these and related questions will automatically make important decisions about the design itself:

1. The product:

- (a) Brief description?
- (b) Various uses?
- (c) Is it one of a "family" of products?
- (d) Should it be packaged as one of a "family"?
- (e) Exact brand name and trade-mark? Registered?
- (f) Margin available for package expense?

2. The market:
 - (a) Who are the ultimate consumers? (Men, women, children, or all three; colored market? Class, religious, or foreign appeal?) What sections of the country is it sold in?
 - (b) What special consumer buying habits must be considered?
 - (c) Through what retail outlets will the product be sold? (Grocery, delicatessen, meat, etc.)
 - (d) What type of operation are these outlets? (Independent, voluntary chain, chain, supermarket, or all of these?)
3. The competitive situation:
 - (a) How do competitive products compare in quality?
 - (b) How do the competitive products compare in price?
 - (c) How do the packages compare? Should they be similar or different in design and color?
 - (d) What is the distribution status of competition?

2. Functions of the Designer

The competent designer, whether operating independently or as a staff member of an agency or fabricator or package user, will determine the answers to the foregoing and many other questions before he puts pencil to paper in laying out his first rough visual. Indeed, the designer must have a working knowledge of packaging operations, package filling, and package handling, as well as of merchandising; and, when he has collected and correlated all the necessary preliminary information, his procedure will be something like this: making a rough sketch of proposed design; making a dummy or model (for structure); conferring with material suppliers; conducting tests for handling, etc., along with the production department; and, with sales, promotion, and advertising departments, conducting market and consumer tests. Thus it will be seen that the functions of the package designer combine and correlate the viewpoints of artist, engineer, and sales specialist.

3. Testing Package Designs

Volumes could be written on this subject. Briefly, these are the questions that must be satisfactorily answered before a package should be launched on the market: Does it attract favorable attention? Does it arouse more than mere passing interest? Does it possess "memory value"? Does it invite purchase?

To find the answers, many concerns conduct elaborate testing campaigns costing thousands of dollars. Armour & Company has a "Consumer Jury" of housewives located in various parts of the United States, to whom they submit products as well as packages to determine their acceptance value. The Kroger Food Foundation obtains the opinions of hundreds of women, by mail and by personal interview, to avoid the possibility of selecting the wrong food or design. Procter & Gamble send girls to exhibit new packages to housewives and explain the use of the product before venturing to obtain widespread distribution. Additional instances could be cited by scores. In all cases a careful technique is worked out to obtain the natural and genuine reactions of potential users—any other kind would be useless.

4. Redesigning Packages

The question is often asked: "Is it wise, or safe, to redesign a package?" Formerly, and not so very long ago, either, redesign was regarded as a dangerous and uncharted sea upon which no one embarked without prayer and meditation. Perhaps that attitude was the result of advertising in which a package was pictured and the public cautioned against the dangers of substitution. But, as packaging has progressed, producer and consumer have come to take package redesign in stride. Today, many businesses have adopted a policy of constant improvement in packaging, both as to design and as to structure, because experience has shown that consumers welcome such changes as evidence of a desire to please.

Interesting, too, is the fact that formerly, when package changes were made, all public mention of it was studiously avoided. An instance is that of a famous soap wrapper on which minute and scarcely noticeable changes were made over a period of some ten years; at the end of that time, the design was completely redone. Nobody noticed it. In contrast is the case of a talcum powder manufacturer, who brazenly advertised—in a day when others thought such a course very hazardous—"We couldn't improve the powder, so we improved the package." This experience, and subsequently that of others, demonstrated that it is good advertising sense to make capital of package changes.

III. THE MATERIALS OF PACKAGING

Packaging calls upon many fields for its raw materials, and a complete package may use as many as half a dozen different substances. One often hears the expression "the packaging industry" when, strictly speaking, there is no such thing. The packaging field is a cross-section of many industries, including producers of raw materials like aluminum ore or pulp wood, and, at the other end of the scale, the converter who prints the aluminum foil for a cheese wrap or the lithographer who reproduces a six-color design on a breakfast food carton.

The principal raw materials of packaging are the finished products of other industries, the basic elements for which come from all over the world. Paper and paperboard, for instance, may use pulpwood from Norway, Canada, Africa, or the United States; the coating on it may be made of casein from South America and chalk from the Dover cliffs. Pigments for the inks and lacquers for protective coatings may come from a dozen countries. The principal source of tin, used universally by the canning industry to coat the steel plate from which their containers are made, has been Singapore. Rubber, used for gaskets for glass jars and sealing compounds for tin cans, comes from South America and the Malay Archipelago. France has the world's largest deposits of bauxite, the ore from which aluminum is refined, although Arkansas supplies the bulk of production in the United States. Plastics are synthesized from organic substances found plentifully all over the globe.

From the foregoing quick and cursory summary, it is easy to understand why a world-wide war is accompanied by shortages of packaging material. Transportation

is disrupted; territory changes hands, and important sources temporarily supply the enemy; and armed services make imperative demands for the same materials needed for civilian packaging, demands of necessity taking precedence. As this is written in 1943, no less than 58 of the materials used for making packages either are entirely forbidden for that use or are under restrictive regulations. See Fig. 63, page 445.

Such a condition makes a search for substitutes imperative. Research laboratories of package users, package makers, and raw material suppliers have responded. New types of paper have appeared to take the place of metals, foils, and rubber sheeting. Protective coatings applied to paper and paperboard provide containers which in some respects serve as well as tin cans. Glass is used extensively; and, although metals and plastics are restricted for closures, caps of paper have come to take their place. War necessity has stimulated ingenuity and inventiveness. Which of these new developments have come to stay is anyone's guess. Undoubtedly some of them will win a permanent place; but in all probability when materials now scarce become available again, the packaging field will return to many of its accustomed forms of containers.

IV. KINDS OF PACKAGES

1. Containers of Paper

This versatile material is without doubt the most important material in the packaging field, certainly for the packaging of foods. It lends itself to many shapes, forms, and purposes, too many for anything but a superficial treatment.

(a) *Bags and Envelopes*

These may be of the simple flat construction, satchel bottom, square type, or automatic self-opening variety. The last is probably most commonly used in bulk packaging; the other three types are more common as printed and decorated containers for branded products. Bags may be made of kraft paper merely to carry goods from store to home, or they may be of substances like glassine, vegetable parchment, waxed paper, or Cellophane. Bagmaking has become so highly specialized that multiwall or laminated types can be fabricated, which, by means of heat sealing, are sufficiently gasproof so that even the aroma of coffee can be preserved for a surprisingly long time. Special types of bags or envelopes are made with sufficient moistureproofness to serve for dehydrated foods.

The bag is an economical method of packaging. Bagmaking machinery has been so perfected that some types are obtainable as low as 25 to 35 cents per thousand. Printing processes have been developed by which elaborate designs and identity features may be excellently reproduced. Bags of transparent material, in addition to affording colorful printed matter, permit visibility of contents, which is an important item with some products.

(b) *Wrappings*

Almost as diversified in type and function as the bag is the wrap, which may also be made of a wide variety of materials such as glassine, waxed paper, vegetable parchment, and Cellophane. The wrap is used for bakery products, for cheese and butter, for candy bars, and in conjunction with cartons and paper boxes as an inner or outer protective member for cereals and similar products. Recently, many stores have adopted the practice of packaging meats in special types of transparent wrappers, so that consumers may serve themselves from refrigerated cases and avoid the long and tiresome wait too often experienced at the meat counter. Wraps, like bags, are economical forms of packaging. Heat-sealing methods have been contrived for use with wraps, and products like processed cheese are effectively packaged in them (see Fig. 64, page 446). But, for the most part, wraps are most serviceable for packaging quick turnover items.

(c) *Set-Up Paper Boxes*

The term refers to any rigid paper box delivered in finished form, ready for inserting the product without further fabrication. This form of package is more widely used for stationery, cosmetics, hosiery, and the like than for food products, though it is the standard package in the confectionery field, and is sometimes used for fancy preserved fruits and the gift packaging of fruit cakes and other specialty bakery products. The set-up box is formed of nonbending boxboard, and usually has an outside wrap of decorative paper or bears a lithographed design.

(d) *Folding Boxes and Cartons*

For convenience, economy, and sales effectiveness, the folding carton has features which make it a very widely used type of package, particularly in the food field. It may be made in an almost infinite variety of styles, though these may be reduced to three basic types, namely, end opening, tray construction, or top opening. Ends may be sealed, lock tuck, or plain tuck, or a combination of any two of these. One of the chief advantages of this style of package is the fact that the boxmaker delivers it flat, thus saving storage space until it is needed for use. All sides or panels may be employed for design or sales copy. The paperboard used may vary in thickness or quality, depending on the product it is to contain. The box may be constructed with a window for visibility, if desired. The outer surface may be given a protective coating, a high gloss with lacquer or varnish; or a *de luxe* finish can be imparted by laminating with cellulose sheeting. Often a package may consist of a folding box or shell of plain or printed boxboard, inside of which is a bag or envelope of protective paper like parchment, waxed paper, or glassine, while outside may be another wrap of wax, or glassine, like the cereal package. Another form, called the "tight wrap," has an outer paper wrap which is pasted all around after the box is filled. This last type of package is frequently used for prepared cake flours and similar products which need protection against moisture, sifting, and infestation. See Fig. 65, page 446.

Folding boxes may be made of a special stock and either coated or impregnated with wax to resist or retain moisture. Some dehydrated foods make use of packages of this description. Butter, lard, oleomargarine, and similar products which must be refrigerated throughout distribution and use, make extensive use of this type. Frozen foods processors have been quick to see the advantages of a wax coating. Manufacture of these wax-coated cartons requires special equipment and craftsmanship.

(e) *Liquidtight Paper Containers*

In use for a number of years, this kind of package has assumed greater importance recently because of shortages of metals. Cheese, butter, ice cream, pickles, and milk are some of the products for which this useful type of container was originally developed, and many others have since been added. The liquidtight paper container is especially adapted to semibulk merchandising, and for products of a perishable nature or those requiring refrigeration. It is made of a fine grade of bleached sulfite, coated with wax or some similar substance to insure moisture retention. A variety of forms are obtainable, square, cylindrical, truncated cone, etc., most of which are almost rigid. Because of the way in which they are used, they must meet a high standard of sanitary requirements, and must be protected against contamination throughout storage and market handling. They may be colorfully decorated, the printing usually being done before the protective wax is applied.

(f) *Fiber Cans*

Dry products have long been packaged in fiber cans. More recently, development of coating and impregnating materials for treating the interior of these cans has made it possible to extend their usefulness. With such treatment, they can be used even for lubricating oils and sirups, as well as for spices, cereals, and seeds. In shape, structure, and coatings available, a wide variety are obtainable; the nature of the product to be packed determines the choice. Structurally, fiber cans are either spirally or convolutely wound. In the former case, ribbons of fiber are wound around a mandrel diagonally, the number of plies varying with the thickness desired, and the resulting tube being of almost any length desired. The convolute tube is wound on a mandrel which revolves, the number of revolutions corresponding to the number of plies needed. In either case it is possible to obtain almost any diameter, thickness, or height. Shapes may be round, square, or oval. Ends are made in a variety of ways, sometimes of paper or, when it was available, of metal. Paper caps are of pressed fiber, and it is possible for the label to be applied after the cap is put on so as to form a seal for the package. Metal lends itself to a variety of tops for fiber cans, among which are friction top, slip cover, and screw top. Plain metal tops may be fitted with pouring spouts or dispensing devices.

(g) *Coatings and Laminations*

Considerations of economy and the necessities of war have stimulated developments in the field of coatings and laminations. Technical research has produced resins, lac-

quers, and plastic coatings which may be applied to paper or fabrics to impart qualities of structural strength and resistance to moisture, acids, and corrosion—in short, practically all the properties enumerated earlier in this chapter. For example, a fine-mesh muslin fabric treated with a thermoplastic coating has been made into a bag for a heavy malt sirup. This bag, resembling nothing so much as a sofa pillow, is put into a double-wall corrugated carton, the combination providing a container which at about half the cost takes the place of a metal drum almost unobtainable in wartime.

Most interesting are the number and character of laminations that are appearing. One finds cellulose sheeting of one type (and there are at least eleven different kinds used in packaging) laminated to another sheet of the same or a different type. Another variation may be glassine laminated to cellulose sheeting, kraft laminated to metal foil. The permutations and combinations are almost limitless. The laminations may run as high as five different substances. For instance, one company produces a sheet of protective wrapping consisting of kraft, asphalt, metal foil, lacquer, and Cellophane. Each one of these substances contributes a desired element: the kraft makes for strength, the asphalt for temperature resistance, the metal foil for opacity and malleability, the Cellophane for moisture resistance, and the lacquer forms an inner protective coating. In short, someone discovered that when two sheets of wrapping material are glued together the combination has qualities of strength and appearance which neither sheet has by itself; and a new chapter in packaging was written. The end of that chapter is nowhere in sight.

2. Metal Packages

The most common metals used in packaging are steel, aluminum, lead, and tin. Mechanical ingenuity and mass production methods have become so highly developed that metal packages of every kind and description can be produced very quickly and economically. One drawback about an otherwise perfect packaging material is that war makes its imperious demands for the same metals, with the result that, in wartime, substitute materials must be sought.

The so-called tin can, of almost universal use (it has been estimated that 17,000,000,000 tin packages are used each year), really contains very little tin. Only about 1.5 pounds are normally used to coat about 80 pounds of the sheet steel which is called tin plate. This coating is sufficient to prevent rust and possible chemical action after the can has been filled and sealed. Besides, the tin assists in the soldering operation. Tin is applied to the tin plate by the hot-dip method or electrolytically. Sometimes lacquer or other coating, in addition to tin, is used. Of late, substitute coatings, notably one called Bonderite, have appeared, to take the place of tin altogether.

The principal use for the tin can is in the packaging of fruits, vegetables, and beverages that must be hot processed, pasteurized, or sterilized after the cans are sealed. Most of these cans are cylindrical, as that shape provides maximum resistance to internal and external pressure and strains. In times past, tin cans have been made in a needless variety of shapes, sizes, and dimensions, largely to satisfy the desire for

something distinctive. The Division of Simplified Practice of the United States Bureau of Standards called a timely halt to this ridiculous practice when it recommended a reduction of sizes to a list of some 35 or 40 different shapes. War restrictions have called for a still further reduction.

Other than cylindrical shapes are common. Consumer habits, as well as manufacturing customs, to some degree are responsible for the flat can in which sardines are packed; for the oblong can, short or tall, in which asparagus comes; and for the tapered package traditional for corned beef. But whatever the explanation, the metal lends itself to fabrication to suit almost any purpose or product, from the little flat preserved-ginger package to the large oil or sirup drum.

The closures vary, too. The can in which fruits and vegetables are hot processed has a side seam sealed with solder and the ends hermetically closed with a sealing compound of which rubber is the base. Pint and quart sirup containers have friction tops. The baking powder can has a slip cover. The spice can has a sifter top. The metal beer can has a crown cap. The preserved-ginger box has a hinged top. The variations are as endless as the material is adaptable, and include screw caps, dispensing devices, and pouring spouts.

Aluminum has rapidly come to the fore as a packaging metal. It is light, easily worked, and capable of being fabricated in many different forms, including the possibility of combination with glass and plastics. Until recently, it has been a more expensive material than tin-coated plate; but some packaging authorities predict that after war needs are relieved the increased productive facilities in the aluminum field will make that metal a close contender with tin for a preferred position in packaging.

The three ductile metals (lead, tin, and aluminum) are extensively used in two other forms, namely, as sheets of metal foil or extruded in the form of collapsible tubes. The latter, however, is not used in the food field to anything like the extent it is found in the drug and toiletry field. Lead foil is frowned on for use with some foods because of its toxicity, but it can be coated or laminated to obviate this difficulty. Foils are particularly useful because of their ability to resist light and heat as well as retain moisture. They can be used in the form of wrappings, bags, or envelopes.

All in all, the advantages of metal packages are so outstanding that it may be difficult for substitutes, however ingenious, to displace them permanently. It is quite probable that some of the substitutes may be retained after the imperative war need for them has passed, though it would be difficult to predict which ones these would be. It is entirely safe, however, to assume that the packaging metals will always hold an important position in this field.

3. Glass Packages

To some extent, glass and metal containers are interchangeable, though each has its own advantages. Chief of these, for glass, is the element of visibility. Only with opal glass is this advantage entirely lost, although this type of glass is more common in cosmetic packaging, while blue glass is more common for drugs and medicines. Amber

and green, however, are sometimes used for pickles, preserves, condiments, and soft drinks. Those colors permit some visibility of content and impart a certain attractiveness of appearance, besides helping to prevent fading of the product color due to the effect of direct sunlight. Green glass inhibits spoilage by preventing rancidity in oil-bearing foods. See page 411.

Glass containers, like metal packages, occur in a wide variety of shapes. To some degree, these shapes have come to be identified with various lines of business, although considerations of utility have also had some influence on the development of certain types. Milk bottles, for instance, have traditionally held to a characteristic form, and efforts to change to others or to other materials have met with some resistance. Catsup and pickles persistently appear in narrow-neck bottles. Wide-mouth jars are used for coffee, preserves, and of late for "canned" fruits and vegetables. Beer bottles and those for carbonated beverages have shapes that seem to be reserved for them exclusively.

Engineering considerations are involved in this matter of bottle design, too. The beer bottle, for instance, must not only withstand rough handling and re-use, but it must be built to undergo heavy internal pressure due to carbonation. Most shapes of glass containers are blown, and the moulds are carefully designed so that the shoulders and corners have sufficient strength and thickness to take the shocks. Other forms, such as wide-mouth jars, may be pressed in a manner resembling the manufacture of metal castings, in which case the side walls and the mouth permit the mold to be withdrawn after forming the body. In the interests of conservation, war regulations "froze" glass moulds to a comparatively small list of shapes, thus making a degree of simplified practice compulsory for the duration of the war.

The glass package requires a closure, and, it should be added, one with a tight seal. With packaging materials plentiful, this is no problem; but shortages of metals, cork, rubber, and plastics have caused a search for substitutes.

The cork stopper is probably the earliest type of closure. It is made in various shapes, *e. g.*, straight cut, tapered, topped, fitted with sprinkler devices, daubers, applicators, etc., depending on the contents of the bottle. Wide-mouth jars and tumblers make use of metal caps of the screw type and lug type, the vacuum seal, and the snap cap. Metal closures may also be used on narrow-neck glass containers. Beer and carbonated beverage bottles use the crown cap of metal, which is crimped on. Plastic closures may be made for either narrow-neck containers or for wide-mouth jars.

Cork ordinarily requires no supplementary material to form an adequate seal. Closures of metal and the plastics need an inner liner. In the crown cap, for instance, will be found a thin disk of cork, and the pressure of the metal against the resilient cork layer forms a tight leakproof seal. Other materials used for inner liners are rubber gaskets, foil, plastic sheeting, and treated papers. These vary in material and thickness, depending on the requirements of the product to be packed.

War shortages have stimulated the development of closures and liners made of available alternate materials. Some of these may conceivably be retained even when metals and other scarce materials again become plentiful. Notable among them are in-

genious contrivances of paper, impregnated or coated to retain moisture, resist corrosion, and perform all the other important functions of the materials they are replacing.

V. PACKAGING OPERATIONS

The term "packaging" goes far beyond considerations of material, structure, shape, and design which we have been discussing. It includes also all those operations necessary to get the product into the container quickly and economically and in deliverable condition. Those operations many times are the deciding factor in the acceptance or rejection of a package suggestion, particularly as to its form or material. For instance, when the government ordered drastic reductions in the amount of metal permitted for crown caps, everybody in the beverage field, and many outside of it, began a frantic search for substitutes. An inventor, with more enthusiasm than experience, approached a big bottler of soft drinks with a suggestion: the use of a convex-formed piece of fiber which would be inserted into the bottle, the pressure of the carbonated liquid forcing it up into the neck of the bottle, forming a perfect seal. The bottler admitted that it would work, and the material itself would be very economical; but the inventor was somewhat taken aback when the bottler challenged him to provide workable machinery and methods for capping their normal production of a million bottles per day.

1. Storage and Handling

Improper storage and handling of packaging material, prior to its actual use, can be responsible not only for losses of the material itself but, of equal importance, losses of man-hours and machine-hours in the filling operations. If possible, deliveries should be arranged so that not too much material is on hand at one time; but equal care must be taken not to run out. The storage room should be convenient to the packaging line, and operations should be planned for minimum handling. Seldom is it possible to obtain all the required material from one concern: bottles and closures come from one source, cartons from another, metal cans from another, and labels and shipping cases from still others. The packer must coordinate all his materials deliveries to keep his production running smoothly.

Conditions of storage are important. Dust, rough handling, dampness, and temperature fluctuations are the hazards to guard against. Dust will contaminate any kind of packaging material and render it unfit for use with foods. Rough handling will dent metal containers and break glassware, even though the latter may be delivered in cases. Dampness will cause cartons to warp and labels to wrinkle, and distort the shape of all paper containers and shipping cases. Temperature changes will cause labels, particularly if pregummed or varnished, to block, that is, to adhere to each other in a manner that may render them entirely useless. Packaging material is property. It should be respected and safeguarded.

2. The Production Line

Straight-line production is the ideal of every production man. Reduced to its simplest terms, this merely means that the operations follow each other in logical sequence and order, without any retracing of steps. The line may be straight, or L-shaped or U-shaped, without violating the principle, and the principle is applicable whether the operations are accomplished by hand, by the semiautomatic method, or full mechanization.

Some products call for hand operations. An extreme case would be a fancy package of high-grade assorted dried fruits in a wicker container, with a protective wrapper of glassine or waxed paper. The various products can be assembled, arranged, and packaged only by hand. This type of packaging may be regarded as an art—with prices in direct ratio thereto!

Most food products, however, are produced and sold on a very narrow margin of profit. They must be packaged with maximum economy. In some instances, this may involve a combination of hand operations with a mechanized line. For example, suppose a product to be a dried soup mix packed in a carton, product and package both adapted to a completely mechanized line. But the chicken fat, a necessary ingredient of the soup mixture, is packaged in a gelatin capsule, so that hand operations may be called for.

In reality, it is these considerations of economy which have stimulated mechanical ingenuity. Machine makers have developed packaging machines capable of turning out thousands of packages a day, untouched by human hands, uniform in quantity of content, all ready to follow the channels of merchandising to the hands of the consumer. Typical packaging machines will now be considered, from the standpoint of the general nature of the products they were designed to handle.

(a) Machinery for Dry Products

Dry products appear in every conceivable type of package, as the following list shows: coffee—vacuum metal can, glass jar, carton, paper bag; cocoa—metal can, fiber can, carton with liner; specialty flour—carton with inner liner and outer tight wrap, paper bag, cloth sack; cookies—shell with inner liner and outer wrap, transparent or semitransparent bag; potato chips—glassine or Cellophane envelope; baking powder—metal can, fiber can; spices—metal cans, glass jars, cartons; cereals—waxed paper bag inside of carton with outer wrap.

The list could be extended indefinitely; but, even with such a limited list, several things may be observed. First, of paramount importance is accuracy of fill. Lack of uniform fill is obviously unfair both to consumer and producer. The Food and Drug Administration very properly frowns severely on slack filling of packages; but it should be pointed out that some products settle after packing to such an extent that improper fill can be unfairly charged.

A second observation is that the consistency and character of these various products vary so widely that each requires its own special packaging equipment. The machinery

makers are prepared to supply these demands. For a product of uniform weight and density, the volumetric method may be used. For free-flowing substances, a definitely timed or regulated flow of the product into the container insures uniform fill. For many other products, however, there must be automatic scales with an automatic cut-off. Sometimes, as in the case of flour packed in a bag, a combination of filling methods may be used on machines especially built for the purpose. The first station on the machine may utilize a "worm packer" to fill the container almost full; the next station may be equipped with an accurate scale to finish off the exact weight.

The machines for handling cartons present an interesting variety. Folding cartons may be made in several dozen different styles, usually delivered flat to the packer; and each style requires machinery especially adjusted for it, to perform such operations as feeding the empty cartons into the machine, setting them up, sealing or closing the bottom, putting in the liner or inner bag, filling or weighing, closing the top, and perhaps applying the outer wrap. Separate units may be obtained for each of these operations, or it is possible to use a composite machine to perform all of them, at speeds which may run as high as 4000 per hour.

"Tight wrapping," sometimes performed when the outer wrap has been fully immersed in water, so it will cling and shrink, is useful to package such products as prepared cake flour or cooked cereals. A product of this kind may contain shortening, and must be protected against high temperatures, sifting, and infestation, in addition to all ordinary hazards. The package therefore may consist of an inner liner or sack of waxed paper or glassine, a chipboard shell which may be treated or impregnated to resist vermin, and an outer wrap or colored label bearing the brand and product identity. The inner packaging may be performed by machinery, and quite possibly the outer wrap may be applied by hand, pasted all over the shell, forming a tight seal. Variations of these machines are adapted to wrapping operations for products like chocolate bars, cheese, soap, etc.

Bag filling machines may vary from a single-head semiautomatic type with a capacity of 150 to 200 units per hour to the multiple-head fully mechanized type with a production of 1800 or more per hour. The operations performed by the latter may include feeding the bags into the machine, opening them up ready for filling, filling and weighing the contents, settling and sealing them, and delivering them ready to be packed in containers.

(b) Machinery for Hot Processed Products

By this method, the packaging begins before the processing is finished. Most hot processed foods are packed in tin cans, but of late the shortage of metal has caused many packers to turn to glass. In the main, the procedure is the same. After the preparatory steps of washing and grading have taken place, the next step is filling the containers. Many fruits are hand packed by weight, whereas containers for most vegetables are machine-filled by volume. Tomatoes are packed both ways, which fact does not shed any light on the age-old debate as to whether a tomato is a fruit or a

vegetable. After filling, the cans are heated to drive out the air; or they may be sealed in a chamber under partial vacuum. The sealed cans or jars are sterilized at or near the boiling point, and, after cooling, go through the labeling machines. In the case of most tin cans, the label is an all-round affair, covering the entire can except for the ends, and affording space for elaborate trade-mark and identity designs as well as full information about using the product. Glass jars usually have smaller labels, thus taking advantage of the transparency of the container to display the appetizing character of the contents.

The foregoing paragraph briefly dismisses a type of packaging which accounts for an enormous volume of production. There are over 3000 firms in the United States, scattered throughout the union, ranging in size from the producer of a few thousand cases of perhaps a single vegetable to the giants of the industry with plants in all the agricultural centers and whose output includes every type of fruit or vegetable grown.

(c) *Machinery for Liquid Products*

Glass is almost the universal material for packages to contain liquid products, and machines are obtainable to handle it in any form. As has been previously intimated, however, production speeds can more easily be maintained when the shape and formation of the container are adapted to rapid machine handling. Bottles and jars with straight sides are less likely to tip. Square corners or round shapes are better than oval. Flat surfaces are labeled more readily than irregular curved surfaces.

Food laws very properly require containers of glass to be washed before filling, and here again machines play their part. Some of these blow a blast of air into the container, effectually removing dust particles, tiny chips of glass, and other forms of contamination. Other machines rinse the glass with streams of water, either warm or cold, or sometimes containing a sterilizing solution. Other machines, designed for containers which are used over and over again, perform operations of soaking, rinsing, and washing, by means of which old labels, bits of adhesives, and various forms of dirt are removed. These bottle washing machines vary in form and include: the single-head air blast, hand operated; the rotary table washing device; the fully automatic straight-line air cleaner; and the five-wide automatic bottle washer. Production speeds range from 20 to 60 or more per minute.

The filling of containers for liquid and semiliquid products is done by machines having from one to thirty or forty filling spouts. The single spout filler is usually semi-automatic, and the measuring is done by inspection of fill to a certain level. The more elaborate machines have a metering device which delivers a measured volume or weight, or they may fill the containers to a uniform height. The pressure required varies with the product. Sometimes gravity flow will serve, but more often mechanical pressure is needed. Viscous products may flow properly only when forced by auxiliary devices like auger or vacuum fillers. Automatic cutoffs operate to prevent waste of the product, and provision is also made in a sanitary way to return the overflow to the supply tank in the event of breakage or spilling.

The closures for glass containers, consisting of the corks, crown caps, screw caps, and lug caps already described, all may be applied by machinery. As a rule they are fed from hoppers by gravity flow, and the machines vary from the semiautomatic, hand-operated, screw capping machine with a capacity of a few hundred per hour to the multiple-chuck fully automatic machine capable of applying several thousand per hour.

The packer who uses glass must strike a happy medium in the degree of tightness for his closures. The consumer should not find it necessary to summon the plumber or the fire department to open a jar or bottle; on the other hand, the closure should not invite loss or tampering by being too easy to remove. The machinery manufacturer, aware of these problems, makes the chucks of his capping machines so that they may be very delicately adjusted.

It is as a precaution against tampering that bottlers of wines or liquors frequently use secondary closures which are destroyed on removal. These are of wax, metal foil, or viscose, and their application is usually a semiautomatic or hand operation.

For some products, the security of their crown or other caps is given a tough test before it leaves the production line. Beer, for instance, is pasteurized immediately after capping, and before the labeling takes place. The process takes about three-quarters of an hour, during which the temperature gets as high as 150° F., and the pressure increases to perhaps as much as 90 pounds. Caps that survive this test are quite likely to be able to undergo the hazards of shipping, merchandising, and consumption.

(d) *Machinery for Labeling*

The labeling operation usually follows filling and capping. Some producers are content with a single-face label. With others the labeling is an elaborate affair. Some whiskies, for instance, have a front and back label, a neck label, and a revenue stamp applied as a strip over the closure; in some States a State tax stamp is required; and some manufacturers affix a little plastic or metal token or trade-mark, virtually a labeling operation.

For most of these, machines exist which can speed up the processes. Even for applying the revenue stamps a machine has been perfected, though care must be exercised to prevent destruction of stamps. There is some spoilage of labels with all machines, of course, but it becomes a serious matter when the material is as valuable as revenue stamps.

As with fillers, labeling machines are available in great variety. Depending on one's requirements, it is possible to obtain either a single-head machine for putting tiny spot labels on small bottles or the automatic straight-line labeler capable of applying front and back labels to a dozen or more packages at a time. Accurate spotting of labels is accomplished by various devices; and some of the machines are adjustable for labels varying from the size of a postage stamp to six square inches or more. Capacity will vary from 30 to 200 per minute.

(e) *Conveyors*

Linking the various units in a production line are conveyors in manifold forms. By means of conveyors, packaging materials or products are moved at controlled speeds around corners, from one level to another, from machine to machine, or from department to department. The most common forms are roller (either gravity or powered) and belt.

(f) *Synchronizing a Production Line*

To the production man falls the task of assuring a smooth and uniform flow of goods in the packaging department. The various units in his production line must be geared to each other so that the merchandise does not pile up on some of the operators while others wait for something to do. This calls for engineering skill and planning, for all of the operations cannot be performed at synchronized speeds. Operation No. 8 can be performed twice as fast as operation No. 9, for instance. In that case there are two possible solutions: The unit performing operation No. 8 may be slowed down in speed to match No. 9, or an additional No. 9 unit may be installed. It is not always so simple as that, but the production engineer always has at his elbow the engineering skill of the machinery manufacturers.

(g) *Care of Equipment*

Neglect probably causes quicker obsolescence than use. The war has obliged people to take better care of their equipment; and it has been found that proper lubrication and proper cleaning of equipment pay big dividends. As one machinery manufacturer expresses it, "Equipment should be *catered* to. Design your packaging material so it is easy to handle and care for your machinery." Over and above the sanitary requirements prescribed by law for food producers are the increased efficiency and production speed usually found in a packaging department which is constantly kept in top condition.

VI. PACKING AND SHIPPING

The individual unit packages of a product cannot be conveniently handled, shipped, stored, or distributed in bulk quantities. A further step must follow the packaging procedure which may be distinguished by the term "packing." This refers to the materials and methods used to prepare products for the wholesale market. Quantitatively, the individual consumer units are packed in cases or containers of dozens, two or three dozen, half gross, and gross. Canned goods cases, for instance, almost invariably contain two dozen of the individual consumer units.

Of necessity, the regulations for preparing goods for shipment by common carrier are very explicit and detailed, particularly for less-than-carload (commonly designated "LCL") lots. These regulations cover the materials of which containers may be made for specific products and/or types of consumer unit packages; methods of con-

structing, sealing, strapping or fastening these containers; maximum and minimum sizes, thicknesses, and dimensions of containers; methods of marking; and methods of loading and stacking, with special provisions for explosives and perishables. Obviously, the regulations are concerned not merely with the protection and proper packing of the shipment itself, but also with consideration for other shipments in the car or truck, as well as convenience and efficiency of handling.

Types of Containers

(a) Corrugated and Solid Fiber Cases

This common and most versatile of all shipping containers practically dominates the food field, particularly for domestic uses. In it are shipped canned foods of every description. Containers for glass packed bottles and jars require protective partitions to guard against breakage, but the familiar metal can gets along without them. Sometimes the labels on canned foods become scuffed during shipment, not a very common occurrence, however. Corrugated paper was first patented in 1871; but the paperboard shipping container had a hard fight against the wood box, and it was not until 1914 that it was fully accepted. Since then, however, its growth and use have been very rapid and widespread. Its advantages are a comparatively low initial cost, light weight, convenience in storing flat, ease of sealing and handling, availability of surface for color printing, and prevention of theft because opening of a case practically destroys it.

Corrugated board is made on high-speed rotary machines, into which are fed rolls of fiberboard. Under moisture, heat, and pressure this fiberboard is shaped by corrugating rolls, then faced with single or double kraft sheets. Solid fiber consists of sheets laminated without corrugation. The latter possesses a rigidity and strength out of all proportion to its thickness and weight. The former, perhaps not quite so sturdy, has a resilience which provides a cushion against shocks in handling. Both types may be cut and scored to form containers of almost any size and shape. In either case it is possible, if desired, to introduce special liners to provide moisture protection. Either kind of board may be attractively printed.

The space and weight saving qualities of corrugated and solid fiber shipping containers have been fully recognized during the war emergency. Early shipments of overseas supplies revealed serious deficiencies in structural strength and moisture resistance which were very frankly placed before the manufacturers of these containers. Cooperative action developed new protective coatings for application to surfaces and edges of board, new adhesives, and new methods of construction and sealing which resulted in what has been dubbed the "V-Box," a container as nearly weatherproof as it is possible to make, undeniably a shipping container advance which will outlast the war. See Fig. 66, page 447.

Under the same stimulus of man power and materials shortages, advances have been made in specialized containers. Collapsible and returnable fiberboard cases for eggs,

boxes for fruits and vegetables with the same advantages, moulded pulp containers for apples, baking boxes with replaceable inner container for bulk meats—these are among the developments which will find a permanent place in the food packing field.

(b) *Wooden Boxes and Crates*

It would probably be difficult to displace this material from certain fields in which it is supreme, notably packing for export shipment, as well as for packing many fresh fruits and vegetables. Boxes of wood are admirably suited for products that must be refrigerated in transit, as well as those which must "breathe" while traveling.

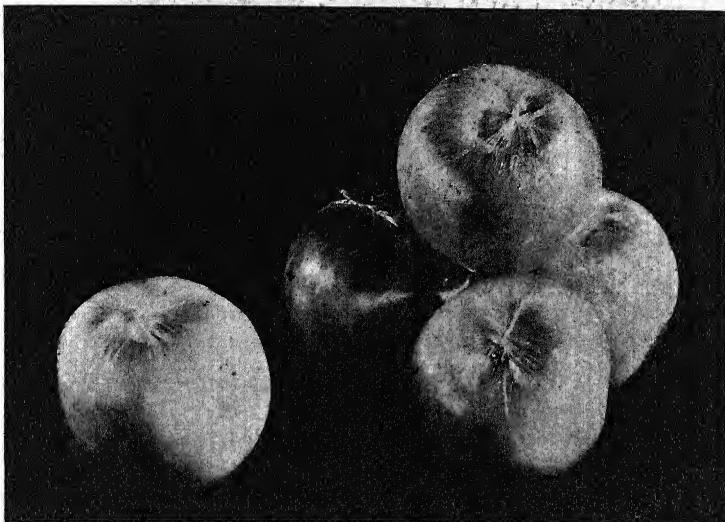


Fig. 63.—Pliofilm is a plastic sheeting which will play a large role in postwar packaging, particularly as a protective wrap for fresh fruits (see page 432).

Containers for products such as head and leaf lettuce, fancy table grapes, and the like must also be rigid enough to withstand crushing that would ruin the contents.

(c) *Metal and Fiber Drums*

Used to some extent for bulk shipment of sirups, ice cream, and dairy products, these containers are not so essential in the food field as they are for lubricating oils and heavy chemicals. If material shortages become sufficiently acute, however, to bring about a temporary return of bulk merchandising, some recent developments in substitute drums may prove to be lifesavers. One of these is a pillow-in-a-box for shipping a heavy, viscous malt syrup formerly shipped in a 50-pound metal drum. The new container is a muslin sack treated to retain liquid contents and provided with a heat seal. This is carried in a corrugated shipping box of double strength. Adopted first as a

makeshift device, it is serving so well that its originators doubt if they will return to the metal drum even when they can.

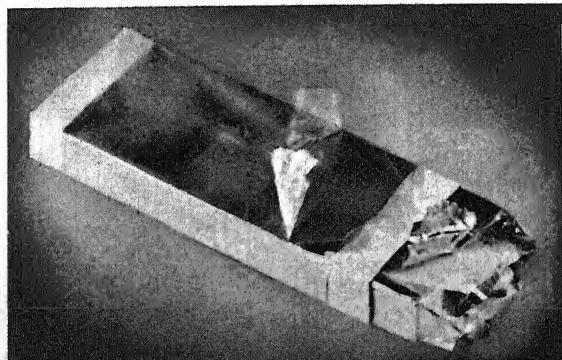


Fig. 64.—Unit packages of glassine laminated to lead foil, fabricated to form moisture- and grease-resistant pack for products like cheese (see page 433).

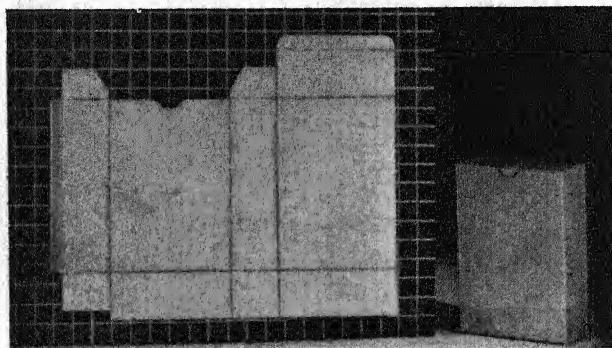


Fig. 65(a).—Tuck-top seal-bottom shell with tight wrap (see page 433).¹

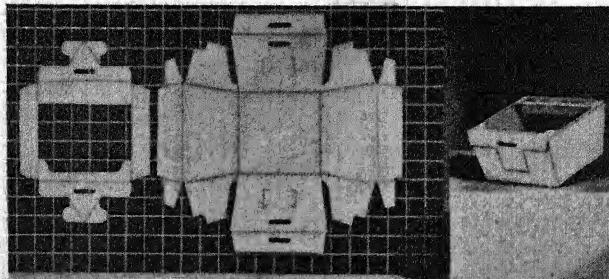


Fig. 65(b).—Berry and vegetable carton (see page 433).²

¹ *Packaging Catalog*. 1943 ed., fig. 6, p. 86.

² *Packaging Catalog*. 1943 ed., fig. 29, p. 96.

Metal drums have distinct advantages for certain products. They withstand the roughest treatment, and have a long life. It is a matter of serious doubt, however, that the consuming public would willingly part with the advantages of individual packaged units to such an extent that a wide use of metal or fiber drums would appear in the food field.

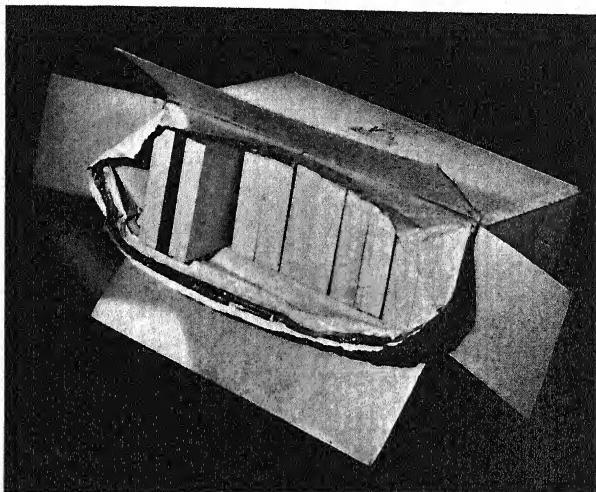


Fig. 66.—Weatherproof fiberboard shipping container with protective bag of laminated, kraft, crepe, and asphalt, used for overseas shipment of foods and medical supplies (see page 444).³

(d) *Supplementary Materials*

For some products, supplementary packing materials are essential. Fruit boxes and baskets for export may require wire binding or steel strapping. Fancy fruits, cake ornaments, and similar articles may need to be wrapped in special protective pads and cushions. To the comment that this seems a heavy expense, the answer is easily presented: How much greater would the loss and damage be without such protection?

VII. CONCLUSION

After all, the function of protection is paramount, and the primary purpose of all packaging and packing is to make sure that a product reaches the ultimate consumer in usable and serviceable condition. The compulsive force of pure-food laws and sanitary regulations has brought about an improved condition in the service which the food industry renders to the consuming public, but of at least equal force is another factor that guarantees continued improvement. That is the force of competition,

³ *Modern Packaging*, October, 1943, p. 84.

which permits no one to ride smugly and complacently on past achievements. Under a system of free enterprise anyone is free to enter any business at any time and obtain a share of the patronage of the public through the performance of a service that is better or cheaper than that being given by those already in the line. Competition, either actual or potential, insures attention to the minutest details. And by no means least among these details is proper packaging.

PART VI
PRODUCTION

Chapter XV

TECHNOLOGY OF CEREAL GRAINS

W. F. GEDDES

St. Paul, Minnesota

I. BARLEY

1. Milling

(a) Pot and Pearl Barley

Most of the barley which goes directly into human food is consumed in the form of pot barley and pearl barley, in the production of which barley flour is a secondary product. Barley flour, as well as barley grits, is also made by a gradual reduction roller milling process similar to that employed in milling wheat to flour.

Pot and pearl barley are both manufactured by gradually removing the hull and outer portion of the barley kernel by abrasive action; the pearling or decortication process is carried further in the manufacture of pearl barley. To produce the highest quality demanded by the consumer, pot and pearl barley must be made from barley which is free from discolored kernels and foreign matter; coloring matter must be absent from the bran layers; and the endosperm must be as white as possible. Well-filled high-grade barley of uniform size is desired; uniformity in kernel size is important because the finished products must be produced in definite sizes.

The manufacture and composition of pot and pearl barley have been described by Le Clerc and Garby.¹ The flowsheet given by these authors is reproduced in Fig. 67. Before pearling, the barley is thoroughly cleaned and is sometimes also classified according to kernel size.

A common type of pearling machine consists of a cylindrical millstone which revolves at about 450 r. p. m. and a perforated cylinder which runs in the opposite direction at about 30 r. p. m. A sheet-iron casing encloses the revolving stone and perforated cylinder. The holes in the perforated cylinder are smaller than the grain, their object being to turn the grain over and over while the rapidly revolving millstone grinds off the hull. The machine operates automatically on the batch principle. Valves on the spout feeding the pearler are operated by cams on the machine so that a batch of three-quarters of a bushel is automatically allowed to pass into the machine at fixed intervals. Each charge of grain is automatically held in the machine

¹ J. A. Le Clerc and C. D. Garby, *Ind. Eng. Chem.*, 12, 451 (1920).

for adjustable periods between $2\frac{1}{4}$ and $4\frac{1}{2}$ minutes. At the end of the selected time, a valve in the perforated cylinder opens and the pearled grain is discharged. The inlet valves on the spout feeding the machine are timed with the discharge valve in the perforated cylinder so that a fresh batch of grain is admitted just after the pearled grain is discharged.

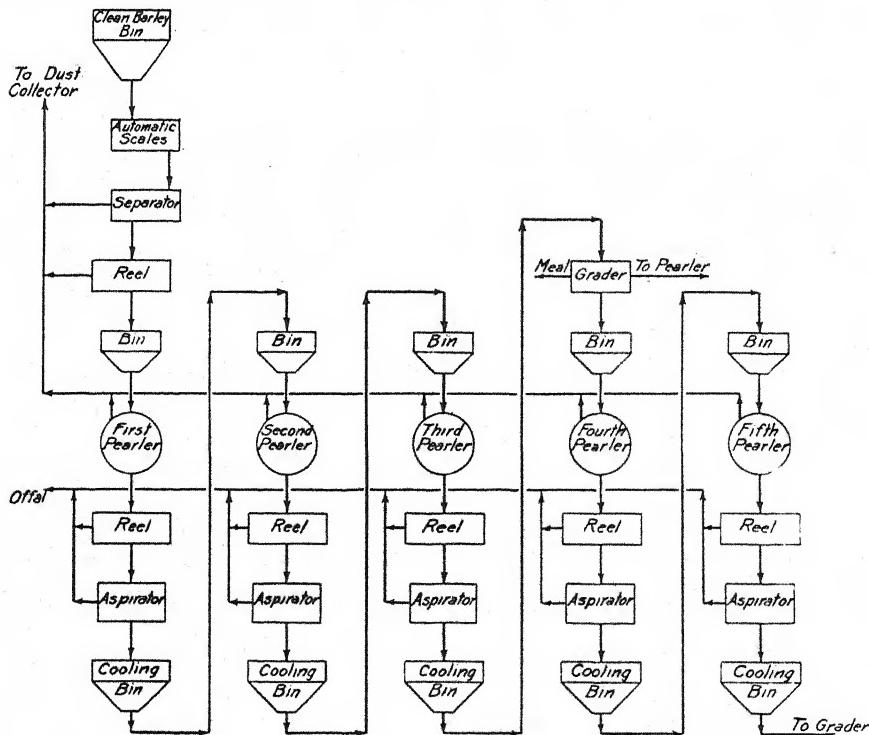


Fig. 67.—Diagram of barley pearling process.¹

Another type of pearling machine consists of 6 to 8 abrasive disks, coated with carborundum or emery, which are rapidly revolved within a perforated cylinder. The hull and outer portion of the kernel are gradually rasped off by rubbing against the disks and the perforated cylinder.

From the first pearler, the mixture of offal and partially hulled barley is sent to a reel which removes the hulls. The barley is then aspirated to remove fine particles and transferred to a cooling bin where the heat developed by the attrition process is dissipated. This series of operations is repeated until a product of the desired size and purity is obtained. After the third pearling, the bran is largely removed, together with most of the aleurone layer; and, at this stage, the product may be graded or classified, and sold as pot barley. When the grain is subjected to 5 or 6 pearling operations, the resulting pearl barley is small, round, and white. After the

last sequence of operations, the product is classified according to size by means of a grading reel. One hundred pounds of barley normally yield about 65 pounds of pot barley or 35 pounds of pearl barley.

The chemical composition of the barley and offals after each pearling operation is shown in Table 33. These data indicate that the first pearling removes most of the

TABLE 33

KERNEL WEIGHT AND CHEMICAL COMPOSITION^a OF BARLEY AND OFFALS AT SUCCESSIVE STAGES IN THE PEARLING PROCESS^b

Product	Wt./1000 kernels, g.	Protein, %	Fat, %	Fiber, %	Ash, %	P ₂ O ₅ , %	CaO, %
BARLEY							
Original barley	42.5	13.2	2.1	5.1	2.8	1.02	0.06
First pearling	39.7	12.9	2.0	2.4	2.2	1.07	0.05
Second pearling	34.1	12.6	1.5	1.4	1.8	0.94	0.04
Third pearling	30.4	10.2	1.2	0.9	1.4	0.81	0.04
Fourth pearling	24.5	10.5	0.9	0.7	1.2	0.68	0.03
Fifth pearling	20.1	10.4	0.9	0.6	1.1	0.62	0.03
Sixth pearling	14.2	9.4	0.9	0.4	1.0	0.56	0.04
OFFALS							
First offal	..	10.6	2.8	23.7	6.9	0.97	0.10
Second offal	..	19.6	6.5	9.2	5.1	1.92	0.10
Third offal	..	16.4	4.9	4.8	3.9	1.81	0.08
Fourth offal	..	14.4	2.6	2.1	2.7	1.37	0.05
Fifth offal	..	13.4	2.0	1.4	2.1	1.14	0.05
Sixth offal	..	12.5	1.7	1.2	1.7	1.00	0.04

^a Results are expressed on a dry matter basis.

^b Compiled from J. A. Le Clerc and C. D. Garby, *Ind. Eng. Chem.*, 12, 451 (1920).

hull but little bran; the second removes more of the bran and begins to scour off the ends of the kernel; while the third largely completes the removal of the bran together with most of the aleurone layer. The fourth, fifth, and sixth offals are essentially barley flour obtained from the outer portion of the kernel after the removal of the hull and bran. Le Clerc and Garby¹ reported that the ash of the first offal contains over 56% silica, while the ash of the second and third offals consists of only about 8 and 5% silica, respectively. On the basis of the decreases in weight and the changes in chemical composition, these authors have computed that 6 pearlings result in the removal of 74% of the protein, 85% of the fat, 97% of the fiber, and 88% of the mineral ingredients of the original barley.

(b) Barley Flour and Grits

In the manufacture of pearl barley, some flour is produced as a by-product. The pearl barley may be ground and sifted to produce a granular product, barley grits, and/or barley flour. This flour is highly refined and is known as patent barley flour. Barley grits and a less highly refined barley flour may also be made by a roller milling,

bolting, and purification process similar to that used in milling flour from wheat. In the larger mills, the hulls are usually largely removed before milling, a process accomplished by passing the barley through a pearly or a hulling machine similar to oat hullers and then sifting and aspirating.

2. Malting²

(a) Barley Types

The types of barley used for malting and brewing differ in European and North American countries. The European demand is for a large kerneled barley with high starch and relatively low nitrogen contents and correspondingly low enzymic activity. In Europe both the six-rowed, Coast types and the two rowed Chevalier and Hanna types are used. The North American industrial requirements are predominantly for a small kerneled barley with a higher nitrogen content and a higher enzymic activity than is used in Europe. The Manchurian type and the smooth-awned varieties derived from this type are used predominantly for the production of malt from brewing, for distilling, and for the food producing industries. The Coast type produced in California supplies a considerable European export market in normal periods of international exchange.³

(b) The Malting Process

The malting of barley is a separate industrial process from the subsequent use of the malt in the manufacturing of fermented beverages, distilled beverages, industrial alcohol, unfermented food products, and medicinals. The malting procedure consists of germinating the grain under conditions conducive to the production of the desired physical and chemical changes associated with the germination process.^{4, 5} This objective is accomplished in commercial malting in essentially five steps.³

1. The grain is cleaned and sorted into uniform sizes which are steeped and malted separately.
2. The barley is steeped by submerging in cold, hard water to bring the kernels to a uniform desired moisture content. (Fig. 68.)
3. The steeped grain is germinated in compartments or drums under suitable moisture, temperature, and aeration conditions to produce proper modification of the kernels (Fig. 69).
4. The germinated grain is dried to a relatively low moisture content to stop germination and chemical changes (Fig. 70).
5. The rootlets, commonly called "malt sprouts," are removed by cleaning.

² Contributed by J. G. Dickson, Professor of Plant Pathology, University of Wisconsin.

³ J. G. Dickson *et al.*, "Grain and Malt Quality of Barley Varieties Grown in the United States," U. S. Dept. Agr. Tech. Bull. In press.

⁴ R. H. Hopkins and C. B. Krause, *Biochemistry Applied to Malting and Brewing*. Van Nostrand, New York, 1937.

⁵ J. A. Le Clerc and R. Wahl, *Bur. Chem. Bull.* 124 (1909).

The malt is stored for reblending or direct shipping, depending upon the industrial demands.

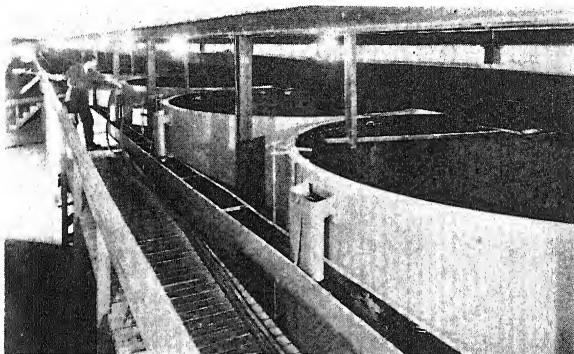


Fig. 68.—Steep tanks for steeping barley. (Photographs of Figs. 68-70 by courtesy of Ladish-Stoppenbach Co., Milwaukee, Wis.)

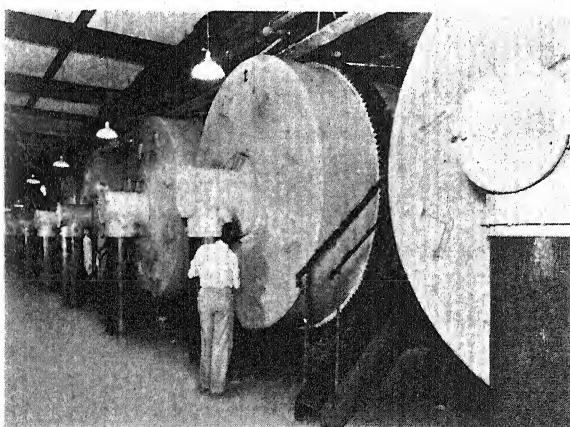


Fig. 69.—Drums in which barley is germinated.

Two general types of malts are produced commercially, brewers' malts and distillers' malts. Brewers' malts are made from barleys of plumper, heavier kernels, with a mellow or friable starch mass, that is—barleys produced in the more humid sections of the spring barley area. These barleys are steeped and germinated at moisture contents ranging from 43 to 46%; the final temperatures used in drying the malt range from 160–180°F. The malts are dried to about 4% moisture. The final moisture and drying temperature vary with the type of barley malted, the malting procedure, and the character of malt desired. The high final drying temperatures used and the low mois-

ture content of the malt tend to reduce the diastatic power of the malt, darken the malt and the wort made from it, and increase malt flavor and aroma. The distillers', or high-diastatic malts, are made from barleys high in nitrogen and enzymic potentialities. Varieties grown in less humid areas and capable of producing a high diastatic power as well as varieties having smaller kernel sizes are generally used for the production of this type of malt. The barleys are steeped and malted at higher moisture, 45–49%, and dried at lower temperatures, 120–140° F., to higher finished moisture contents, 5 to 7%, than the brewers' type of malt.

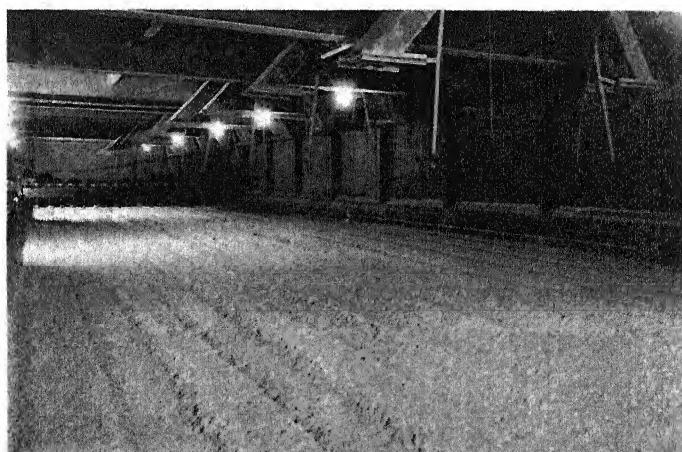


Fig. 70.—Drying kiln in which finished barley malt is dried.

The approximate ranges in composition of the two types of malts produced in the United States are given in Table 34. Since most of the uses of malt are based on its enzyme content, the activation or production of the enzymes during malting may be considered the most important transformation. The other physical and chemical changes are also due in large part to the action of the different enzyme systems during

TABLE 34
COMPOSITION OF BREWERS' AND DISTILLERS' MALTS

Malt type	Extract content, fine grind, % on dry basis	Diastatic power, ° L.	Ratio of wort nitrogen to malt nitrogen
Brewers' malt	70-74	110-140	30-34
Distillers' malt	69-72	160-200	30-36

germination.⁴ Photographs of barley kernels with the hull removed after varying periods of germination are shown in Fig. 71. Photomicrographs illustrating the modification brought about by the malting process are reproduced in Fig. 72.

Ungerminated barley contains small quantities of most enzymes but appreciable quantities of β -amylase, a portion of which is bound to protein and is not water soluble. During germination, the proteolytic enzymes appear to be activated rather early and distributed throughout the endosperm of the kernel. The same appears to be true of the cytases, which change the cell walls to make them much more permeable, resulting in the mellow, friable condition of the dried malt kernel.

The bound β -amylase is freed during germination by the action of the proteolytic enzymes, so that in the finished malt the majority of the β -amylase is in the free state. α -Amylase is found in very small amounts, if at all, in the ungerminated grain, but is elaborated rather rapidly after 2-3 days of malting until the seventh or eighth day.

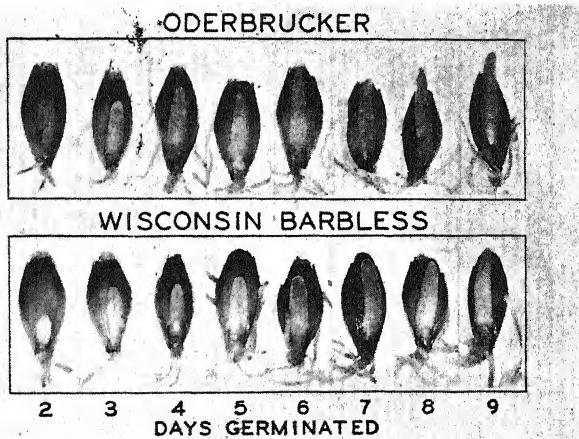


Fig. 71.—Barley kernels with hull removed to show plumule (acospire) elongation at 2-9 days' germination. Kernels steeped and germinated at 16° C. (60.8° F.) and 48% moisture. Magnification, approximately 1.4 times.

In contrast to the proteolytic enzymes and cytases, the amylases are not rapidly distributed throughout the kernel but, at the end of 9 days' malting, are still primarily confined to the germ half of the kernel. The seat of enzyme production appears to be the scutellar epithelium which lies between the embryo and the endosperm.

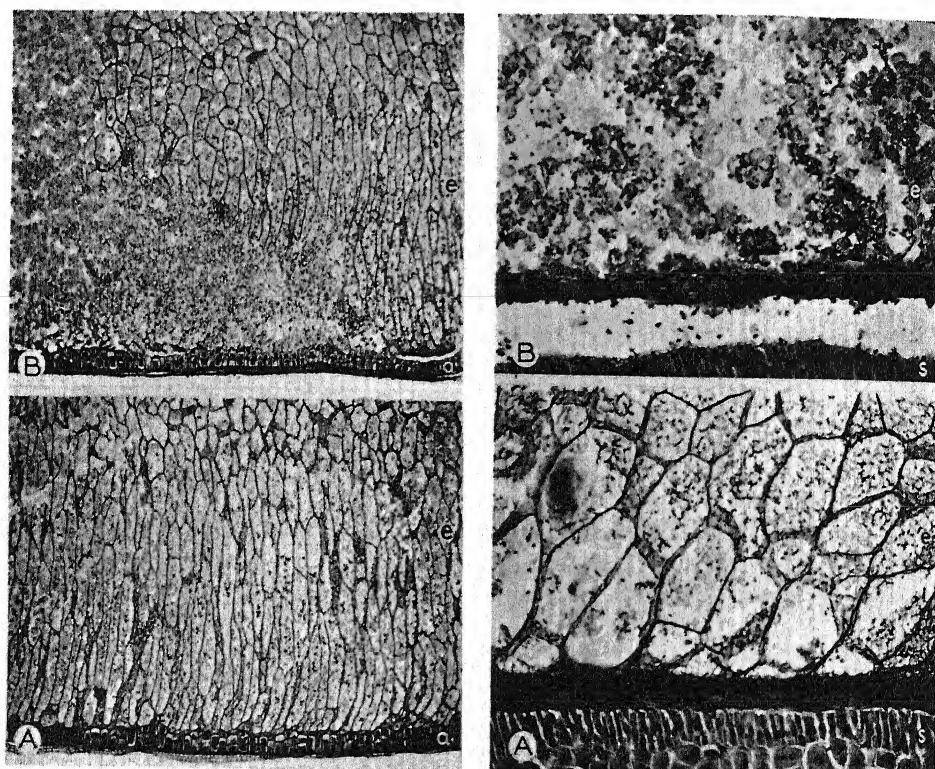
During germination, the starch is attacked to a small degree, approximately 5% being converted to maltose, which is further converted to glucose, fructose, and sucrose. The major conversion of the starch takes place during the mashing of the malt in its use for brewing, distilling, or malt syrup production.

The proteins are attacked to a much greater extent during the malting process itself. Based on cold-water-soluble nitrogen and wort nitrogen after laboratory mashing, relatively more of the nitrogen is made soluble during malting than during subsequent mashing. This would indicate an earlier production and wider distribution of the proteolytic enzymes than of the amylases.

(c) *Uses of Malt*

In the industrial uses of malt, the actions of the starch-splitting and protein degrading enzymes are utilized and controlled by *pH*, temperature, and time to give the desired composition in the finished product.

Brewers' malts are used for the production of beer and ale and, to a lesser extent,



Longitudinal sections of the endosperm along the side of the kernel of steeped barley and barley germinated two days. *A*—barley steeped to 48% moisture but not germinated. The aleurone layer is shown at *a*. The endosperm cell walls and starch granules imbedded in the matrix within the cells are shown at *e*. *B*—similar section of barley kernel steeped to 48% moisture and germinated two days at the same moisture at 16° C. (60.8° F.). The zone of dissolution of the cell walls and starch-imbedding matrix is shown diagonally from the left top to right bottom, with the undigested tissue on the right. Magnification, approximately 40 times.

Highly magnified longitudinal sections of the endosperm near the scutellum of steeped barley and barley germinated six days. *A*—barley steeped to 48% moisture but not germinated. The epithelial layer of the scutellum is shown at *s*. The endosperm cell walls and starch grains imbedded in the matrix are shown at *e*. *B*—similar section of barley kernel steeped and germinated six days at 16° C. (60.8° F.) and 48% moisture. The cell walls and imbedding matrix of the endosperm *e* have been digested during germination. Magnification about 130 times.

Fig. 72.—Photomicrographs of longitudinal sections of the barley kernel illustrating the modification brought about by the malting process.

for evaporated malt extracts and malt sirups. Distillers' malts are employed for starch conversion in the production of distilled beverages and industrial alcohol, and for malt sirups, desizing extracts, etc.

The manufacture of malt sirups, concentrated malt extracts, etc., involves:

1. The solution and extraction of soluble and colloidal substances from the crushed barley malt by means of water of proper hardness and reaction held at suitable temperatures for sufficient time intervals to enable the various enzyme systems in the malt to hydrolyze the desired grain components, principally carbohydrates and proteins.

2. Filtering the solution. The filtrate, or wort, in some instances is boiled to sterilize it and to precipitate unstable and undesirable substances.

3. Further concentration of the wort by means of vacuum evaporators, the process depending upon the final product manufactured.

Malt is used directly in the preparation of certain cereal food products although in proportion to the food products in which sirups or malt extracts are utilized the volume is relatively small. The extensive uses of barley and barley malt are summarized in Table 125, page 628, Volume I.

II. BUCKWHEAT

The chief buckwheat milling centers are located in New York, Pennsylvania, Michigan, Maine, and Ohio in the heart of the buckwheat producing areas. Buckwheat is milled into flour by a roller milling process similar to that used in wheat flour production, but much shorter.

Preparatory to milling, the grain is passed over separators, dried to about 12% moisture, and then put through a scouring machine to clean and polish the grain. According to Coe,⁶ the milling process normally consists of 2 to 3 breaks and 2 reductions, the flour being bolted through an 8XX silk. In order to facilitate the cleanup of the bran, the first break stock is dried to about 12% moisture in a long revolving cylinder containing steam pipes. The flour yield varies from 52 to 78% depending upon the color of the flour and degree of refinement desired. The production of hulls varies from 18 to 26%, and buckwheat "middlings" (feed) comprise the remainder. The hulls are worthless as feed and are used for fuel, as bedding for farm animals, or as a packing material.

In milling for groats, medium sized kernels, obtained by classifying the cleaned and scoured buckwheat over sieves, are employed. These are kiln-dried to about 12% moisture, passed between two millstones which are adjusted to crack the hull with minimum grinding of the groat. The product is then sieved and aspirated to remove hulls and fine particles. The resulting groats are graded into various sizes.

III. CORN

1. Dry Milling

Corn is ground for human consumption by two general methods which are designated

⁶ M. R. Coe, U. S. Dept. Agr., *Circ.* 90 (1931).

as the "old process" and "new process." "Old-process" meal is also known as "water-ground" meal because the mills making it were formerly operated by waterpower.

(a) Old-Process Corn Milling

In the old process, the corn (preferably white dent) is ground to a coarse meal between millstones run slowly at a low temperature, and the meal, especially in many of

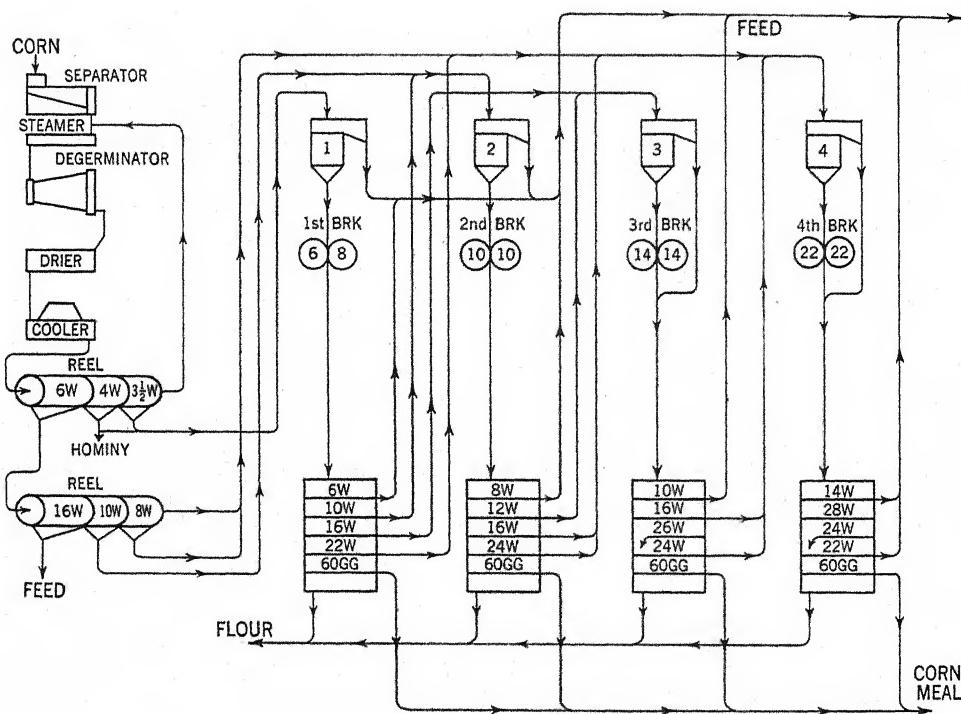


Fig. 73.—Flowsheet of dry-milling of corn in a small hominy mill. (Courtesy General Equipment Co., Kansas City, Mo.)

the small mills, is frequently not bolted. In the larger mills, about 4 to 6% of the coarser particles of the hull are bolted out. This type of meal is therefore essentially a whole corn product and, owing to the presence of the germ, has a rich oily flavor and deteriorates rapidly. The meal is softer and more flourlike than the more highly refined new-process meal, and is preferred by many in the southern States. In many of the larger mills, the corn is dried to from 10 to 12% moisture before grinding; the kiln drying permits more rapid grinding and improves the keeping qualities of the meal.

(b) *New-Process Corn Milling*

The new process of corn milling is characteristic of the North, and is carried out with steel rolls along lines similar to those used in the milling of wheat. The object is to remove the bran and germ and to recover the endosperm in the form of hominy or corn grits, coarse meal, fine meal, and corn flour. Corn grits and coarse meal consist largely of particles of corneous endosperm whereas the fine meal and corn flour are derived chiefly from the starchy endosperm.

Flint varieties of corn are considered too "sharp" for grinding to meal. Dent corn is almost invariably used; both white and yellow dent corn are milled. Since grits used in the manufacture of corn flakes must be made from white corn, large quantities of white corn are milled with the primary purpose of securing grits. The meal and flour are regarded as by-products. U. S. Grade No. 3 corn is the principal grade milled. As corn containing 17.5% moisture is eligible for this grade, it is often kiln-dried before milling.

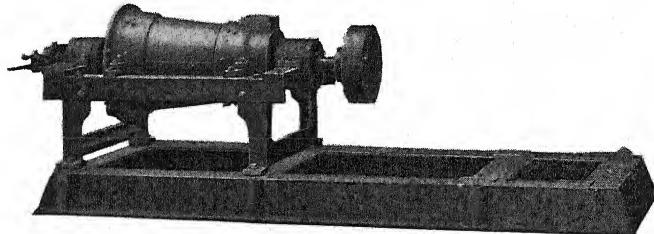


Fig. 74.—Dry-system corn degerminator. (Courtesy Beall Improvements Co., Inc., Decatur, Ill.)

The development and present technique of dry corn milling has recently been described by Stimmel.⁷ A simplified diagram of the process is given in Fig. 73.

Cleaning.—The shelled corn is passed over magnetic separators to remove tramp iron and then thoroughly cleaned over sieves. It is usually passed through a scourer (see page 482) to remove from the germ end of the kernel the tip which is frequently black in color and, if allowed to remain, would cause black specks in the meal.

Tempering or Conditioning.—In order to toughen the bran, the corn is tempered by two additions of water to a moisture content of from 21 to 24%. Following the first addition of water, the corn is allowed to stand for some hours in a tempering bin, after which it is passed through a short conveyor where warm water at 125 to 175° F., or sometimes live steam, is added to loosen the bran and germ.

Degermination.—The tempered corn is next passed through a degerminator (See Fig. 74). This consists of a horizontal, cone-shaped drum which is covered with small steel projections, and revolves at about 700 r. p. m. within a metal housing which

⁷ E. P. Stimmel, *American Miller*, 69, 30 (October, 1941).

is also studded with similar steel projections over a large part of its inner surface; a part of the outer casing consists of one or more perforated metal screens. As the corn passes from the small to the large end, the bran and germ are freed to a large extent, and the endosperm is broken into two or more pieces. The fine particles, which consist chiefly of hull and germ, pass through the perforated housing, while the larger pieces are discharged from the end of the machine.

In some meal mills, the corn is not passed through a degerminator; in this instance, the corn is tempered to about 17% moisture and goes directly to the first break rolls where the germ is largely freed and removed by a subsequent bolting process.

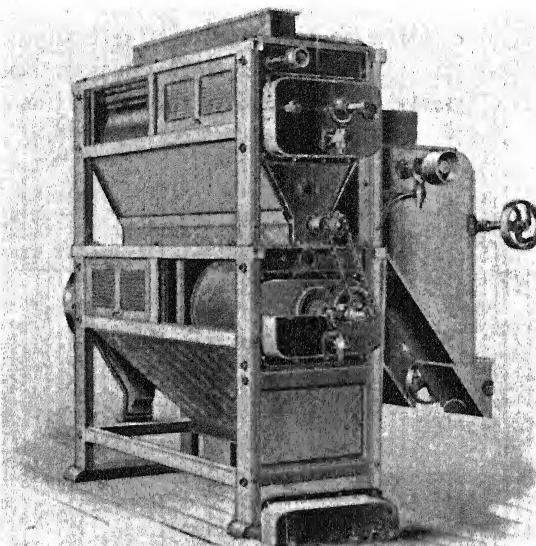


Fig. 75.—Hominy separator or grading reel. (Courtesy S. Howes Co., Inc., Silver Creek, N. Y.)

Both stocks from the degerminator are dried to 14 to 16% moisture in revolving driers equipped with steam coils and then cooled in revolving or gravity-type coolers. When the corn is originally of low moisture content, the stock from the tail of the degerminator may not require drying.

Grading.—The dried and cooled stocks from the degerminator are passed through a hominy separator (Fig. 75). This machine consists of an intricate series of grading reels; it first separates the fine particles (feed) and then grades and "polishes" the larger fragments into four different sizes. Each grade is aspirated by itself; and the light material which is drawn off is deposited in separate pockets.

Aspiration.—From the grading reels the various grades of broken corn are passed through centrifugal-type aspirators which remove the loose bran by means of a strong current of air. Where a commercial grade of hominy is produced, the coarse separation

from the grading reels is sent to a hominy polisher. This consists of a revolving cylinder surrounded by a perforated screen; in passing between the cylinder and the screen, the particles of the stock are polished by rubbing against each other as well as by the abrasive action of the cylinder. The polished hominy is then regraded, and again aspirated. The fine materials which pass through the screen of the hominy polisher and also that removed by aspiration are spouted to hominy feed.

Grinding and Bolting.—The various grades of aspirated corn fragments are reduced to coarse, medium, and fine grits by gradual reduction between corrugated rolls and subsequent sifting or bolting of the chop, as in the milling of wheat. The coarsest stock from the aspirators (unless made directly into commercial hominy) goes to the first break rolls; these are spaced farther apart, have coarser corrugations (5 to 8 per inch), and operate at a lower speed differential than succeeding breaks.

The coarsest grade of hominy is the one most highly contaminated with germ. The object is to free the germ and flatten it between the break rolls, with minimum grinding of the endosperm, so that the germ may be separated by bolting. The successive steps in the gradual reduction process for corn are analogous to those described for wheat (see page 480). Modern corn mills are designed in such a way that grits of any particular size may be taken off, or they may be subjected to further grinding, sifting, and aspirating to produce meal and flour (a more granular product than wheat flour). The various grades of grits or meal are generally dried at 150° F. for several minutes and then cooled before packing. The tailings from the various grindings and aspirations enter the hominy feed; this is often reground in attrition or hammer mills.

The flattened germs, which are separated from the grits and hominy by the bolting process, are now generally utilized for the production of corn oil. The germ is dried to about 2 to 3% moisture, ground, tempered with steam, and passed through expellers (oil presses of the continuous or screw type). The germ cake from which the oil has been largely expressed is frequently reground before packaging.

Hominy or grits which are intended for industrial purposes, such as brewing and the manufacture of wallpaper paste, are flaked. The grits are steamed, passed between heavy-duty, heated, iron rolls, and the resulting flakes dried (but not toasted); as a result, the starch is partially gelatinized.

(c) Yields

The relative yields of the various mill products varies, depending upon whether the main objective is the production of grits or meal and, in the latter instance, whether the corn was degermed before being subjected to the grinding process. In the milling of corn for grits and meal by the degenerating process, the following average yields are typical: grits, 52%; meal and flour, 8%; hominy feed, 35%; and crude corn oil, 1.0%. There is a shrinkage of about 4% which results largely from the differences between the moisture content of the corn and the various mill products. When the corn is not degermed before grinding, a yield of about 20% feed and 72% corn meal is pro-

duced with a shrinkage of about 7%; of the total meal produced, approximately two-thirds is highly refined or cream meal containing about 1.4% fat, and one-third is standard meal containing about 4.7% fat.

2. Wet-Process Corn Milling

(a) *Introduction*

In the wet process of milling corn, the object is to separate the various components of the grain and to utilize them for industrial purposes. When corn was first utilized as an industrial raw material, the only aim was to secure the starch. With the expansion of the industry, processes were developed for the recovery of other substances; it was found that most of the oil could be removed from the germ, and that fiber, gluten, and other materials formerly considered as waste could be utilized as animal feeds. Methods for modifying the physical properties of starch (such as the preparation of soluble starches, alkaline starches, chlorinated starches, and many others) were developed to render it more suitable for specific purposes; in addition, processes were perfected for the conversion of starch into dextrins, corn sirup, and dextrose. Concurrently with these scientific advances, marked progress was made in improving the manufacturing techniques so that, today, the industry carries out a series of extremely intricate and highly specialized manufacturing operations. The plants are bottled up, that is, the water used in separation moves countercurrent to the corn undergoing processing; in its backward flow, the water accumulates soluble matters; after finally being treated with sulfur dioxide and used for soaking or steeping the incoming corn, it is concentrated and added to the various feeds. The magnitude of the industry may be judged from the figures in Table 35 representing the average quantities of corn processed and sales of certain products for the 10-year period of 1931 to 1940, inclusive.⁸

TABLE 35
CORN PROCESSED AND SALES OF CORN PRODUCTS (AVERAGE 1931-1940)

Corn ground.....	70,309,500	bushels
Products sold:		
Cornstarch.....	781,137,300	pounds
Corn sugar.....	559,617,300	pounds
Corn sirup (unmixed).....	1,022,315,000	pounds
Dextrins.....	81,690,700	pounds
Corn oil, crude.....	29,836,600	pounds
Corn oil, refined.....	96,535,700	pounds
Gluten feed and meal.....	543,900	tons
Corn oil meal.....	23,700	tons

(b) *Description of Process*

A simplified diagram of the corn refining process is given in Fig. 76. The following description of the wet-milling industry, limited to a general outline of the steps in-

⁸ Compiled from data given in *Agricultural Statistics* (1941).

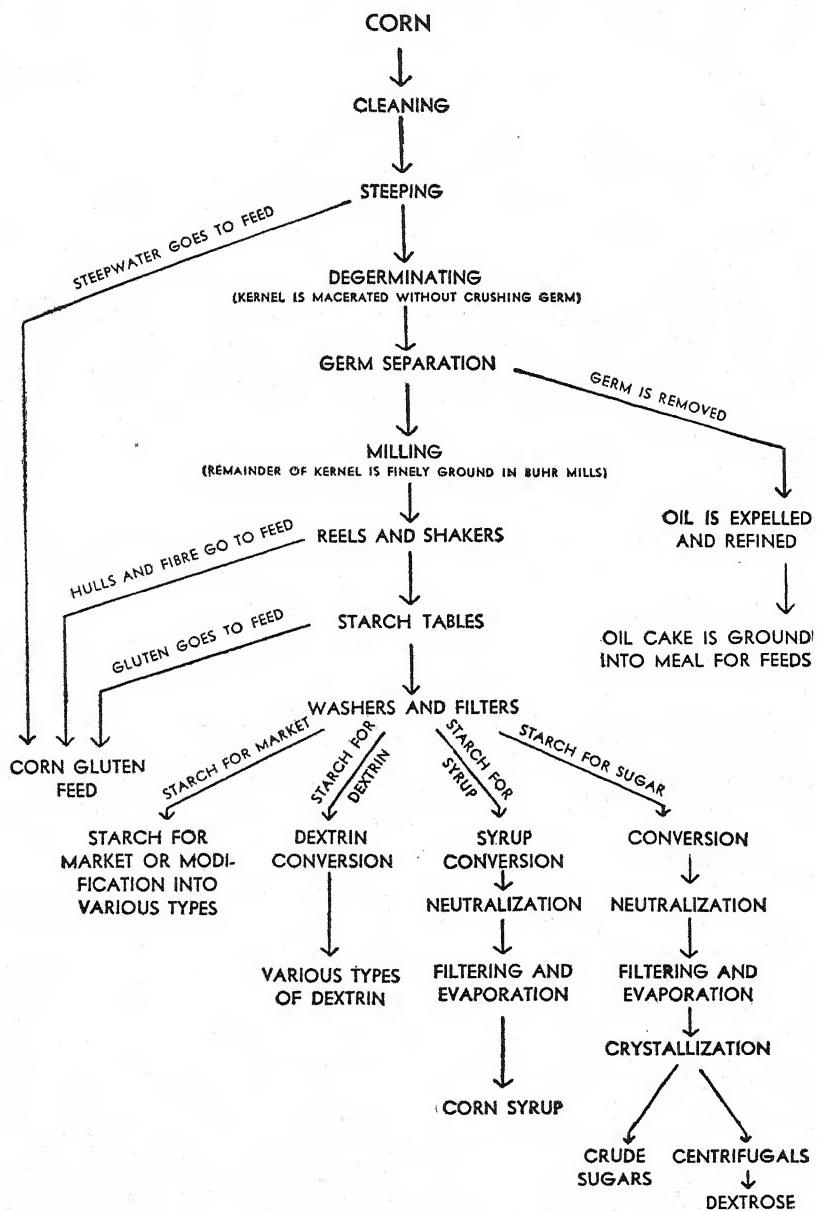


Fig. 76.—Simplified diagram of the corn refining process. (Cut by courtesy of the Corn Industries Research Foundation, New York, N. Y.)

volved in obtaining the primary products from the corn kernel, is based largely on information published by the Corn Industries Research Foundation⁹ and on a series of technical papers by Bartling.¹⁰

Cleaning.—The shelled corn is first cleaned by sieving and aspiration and passed over magnetic separators to remove "tramp" iron.

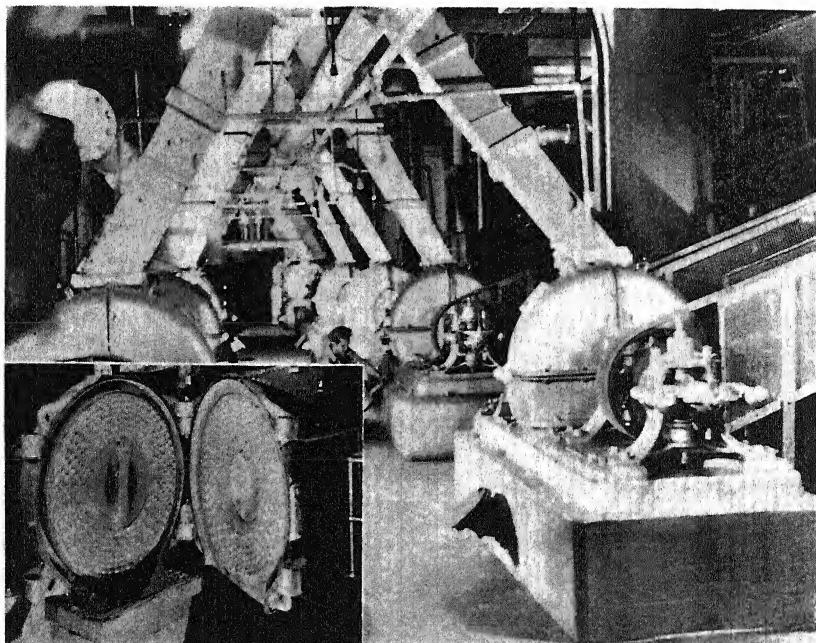


Fig. 77.—Degerminating mills. View of open mill at left shows the studded rotary plates which turn in opposite directions and tear the kernel apart without crushing the germ. (Figs. 77-81 reproduced by kind permission of the Corn Industries Research Foundation.⁹)

Separating the Germ.—The cleaned corn is conveyed into large tanks holding from 2000 to 2500 bu. of corn, and is soaked, or steeped, for 36-48 hours in dilute sulfurous acid solution (0.2-0.3% sulfur dioxide) maintained at approximately 125° F. The sulfurous acid prevents the growth of bacteria, yeasts, and molds which would cause deterioration of the starch and gluten. The steeping treatment loosens the hulls,

⁹ *Corn in Industry*, Pamphlet issued by Corn Industries Research Foundation, New York. (Copyright 1937.)

¹⁰ F. W. Bartling, *American Miller*, 67, 26 (December, 1939); 68, 24 (February, 1940), 42 (March, 1940), 24 (April, 1940), 36 (May, 1940), 40 (August, 1940), 46 (September, 1940), 28 (October, 1940), 25 (December, 1940); 69, 32 (February, 1941), 48 (March, 1941), 34 (May, 1941), 38 (June, 1941), 40 (August, 1941), 46 (October, 1941), 32 (November, 1941), 34 (December, 1941); 70, 38 (February, 1942), 80 (March, 1942), 46 (August, 1942), 62 (September, 1942), 56 (October, 1942); 71, 154 (January, 1943), 74 (June, 1943), 56 (August, 1943), 50 (November, 1943); 72, 64 (February, 1944).

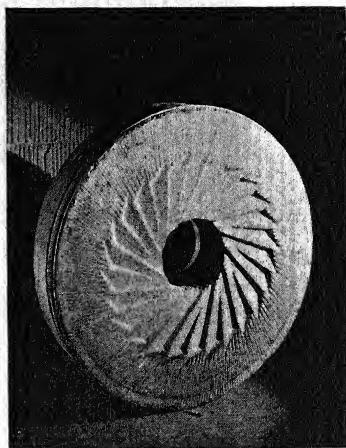
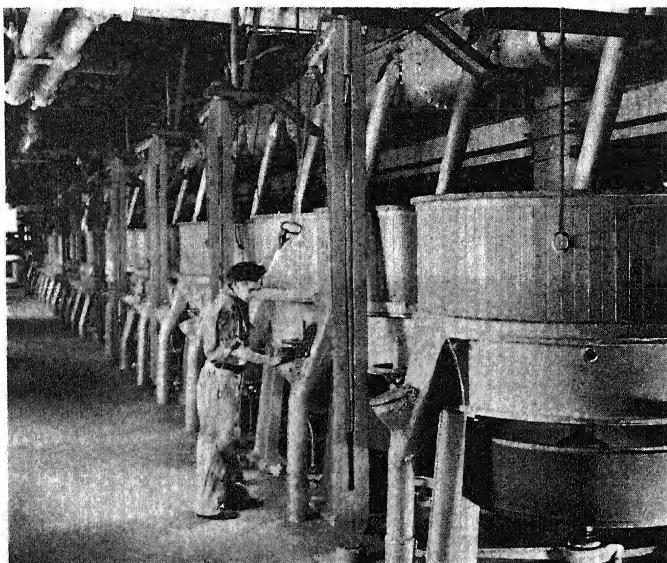


Fig. 78.—Upper photograph shows a series of buhr mills, the heavy stones of which grind the gluten, starch, and fiber into fine particles. Photograph at lower left shows a stone dresser refacing a worn stone; at lower right the finished stone is shown.

softens the gluten, and dissolves much of the soluble mineral matter of the corn as well as some of the soluble carbohydrates and albumins and globulins. The steeping process, however, involves more than the mere removal of soluble substances present in the corn. During steeping, 2-3 times more solids are removed than by water extraction at 0° C.; as the increase is principally in the crude protein fraction and consists largely of amino acids, considerable protein hydrolysis occurs.¹¹ The tanks are arranged in batteries. The steep water is circulated in such a manner that fresh acidu-



Fig. 79.—Reels. Silk, stretched tight on frames, forms the sides; the particles that cannot pass through the silk are tumbled out at the lower end.

lated water introduced into the system first passes through the corn which has been steeped the longest. The spent water drawn off from the most recently filled tank contains about 900 lbs. solid matter per 1000 gal. (4-6° Bé.) and is later concentrated to 25° Bé. or better for use in preparing the feeds.

At the end of the steeping treatment, the corn contains about 42-50% moisture. It is next passed through a Foos mill, a special type of attrition mill or degerminator (see Fig. 77) designed to free the germ without crushing it, loosen the hull, and partially disintegrate the endosperm. Water or low-density starch liquor is fed into the degerminators along with the corn; and a heavier starch liquor is mixed with the macerated corn to form a slurry which may readily be pumped into the germ separators. These are long, U-shaped tanks in which the macerated corn is mixed with a liquor

¹¹ L. Sair and W. R. Fetzer, *Cereal Chem.*, 19, 633 (1942).

maintained at 8–10.5° Bé. and a temperature of 90–96° F. As the suspension is propelled from one end of the tank to the other, the germs, which are of low density because of their high oil content, rise to the surface and are mechanically skimmed off into pipe lines leading to the germ washing reels, where adhering starch is removed. The coarsely disintegrated particles of endosperm which settle to the bottom of the germ separators are removed, passed over shakers or reels to drain off most of the liquor, and fed to a second battery of degerminalators to complete the liberation of the germ. This treatment is followed by a second germ flotation.

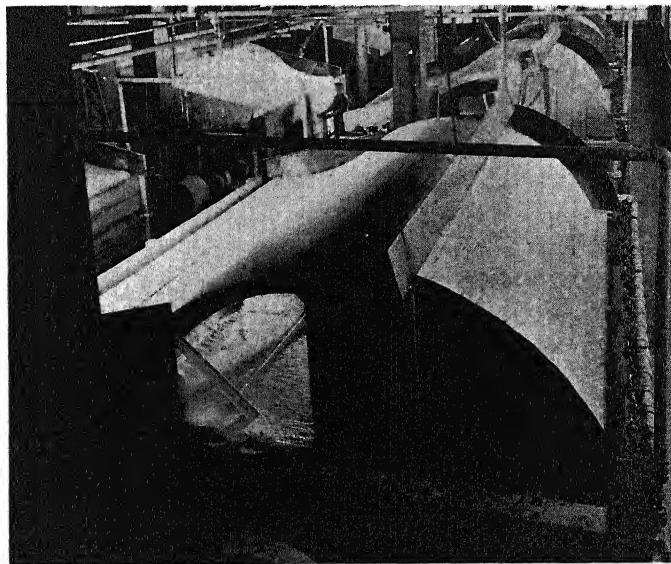


Fig. 80.—Filters or "washers."

Separating the Starch.—After the second germ flotation, the settlings, comprising the germ-free residue of the macerated corn, are passed into reels to remove the major portion of the liquor. The solid residue from the reels is then ground in buhr mills to separate the granules of starch, gluten and hull (see Fig. 78). The ground material discharged from the buhr mills is then washed through a series of reels and shakers. The reels (Fig. 79) are slightly tilted and are open at both ends. The mash is washed in at the upper end and, as it passes through the revolving reels, is successively picked up and dropped on the bolting silk. The starch and gluten are washed through the bolting silk while the particles of hull, or bran, tail over the lower end of the reels. The shakers consist of rectangular sieves fitted with fine bolting silk and are used to remove any remaining fine fibrous material. In some plants, the hulls are removed and washed on reels equipped with relatively coarse copper sieves, and the stream then passed to a series of reels, clothed with bolting silk (No. 17) to separate the fine fiber.

The effluent, consisting of starch and corn gluten, is adjusted to the desired density

(4-12° Bé.) and evenly flowed on to starch tables. These consist of slightly inclined (4-6 in. per 100 ft.), flat-bottomed troughs about 2 ft. wide and up to 120 ft. long. As the suspension slowly flows down the tables, the starch, being of high density, is deposited on the tables, while the gluten flows off the tail end. While most of the starch settles in the troughs to form a long, sloping, wedge-shaped layer, some of it tails over with the gluten. The tabling operations are considered well controlled when the dry matter of the gluten tailings contains 50-55% protein and 30-40% starch; the remainder comprises pentosans, oil, and mineral matter. Ordinarily, 1 to 2 lbs. of starch per bu. corn tail over with the gluten. Mechanical methods have been developed which provide automatic control of the tabling operations. The starch content of the tabled starch is normally about 98% (dry matter basis).

The starch on the tables is freed from its superficial gluten film with a stream of water. The washings are added to the tailings or recycled to the tables. The main bulk of the starch is then flushed from the tables, preferably with warm, softened, and filtered water; frequently the water used at this stage is made up in whole or in part of water from the starch filters. The "green" starch is then washed and dewatered on rotary vacuum drum filters (Fig. 80) or disk filters. The series of washings and filtering processes to which the starch is subjected largely removes soluble materials and brightens the color of the starch; the wash water is re-used in earlier stages of the refining process. The purified wet cake of refined starch normally contains about 42-45% moisture, depending upon the method of filtering, and is either dispersed in fresh water for conversion into various types of modified starches, corn sirup, and dextrose, or dried. The wet starch which is dried is marketed as Crystal, Pearl, Common and Special Powdered starch containing between 6 and 12% moisture, or is processed into gloss or laundry starch, roasted into dextrans and gums, and made into other special products, as described on pages 548, 550, and 558. For many years, starch was dried exclusively in tunnel kilns but these are being replaced by other more rapid methods, such as vacuum rotary batch driers, internally revolving vertical and horizontal air and steam driers, and spray driers. Dried, commercial cornstarches for food purposes usually contain 1.0 to 1.4% nonstarch substances: protein ($N \times 6.25$), 0.30 to 0.40%; ash, about 0.10%; methanol extract, about 0.75%.

By-Products.—The germ which is skimmed off in the germ separators is washed, passed through a moisture expeller, kiln dried to about 1.0% moisture, preheated to approximately 95° C. and the oil extracted in oil expellers which exert a pressure of approximately 4000 lbs. per square inch. The residual oil cake is ground and tempered to form oil cake meal.

The gluten tailings from the starch tabling operations are conducted into a series of primary settling tanks with conical-shaped bottoms. After a time, the supernatant liquid is decanted and the heavy gluten slurry passed through Merco centrifugals, whereby some of the starch which was not deposited on the tables is recovered. (In some plants, Dorr thickeners have replaced the settling tanks; in these devices, the gluten suspension is subjected to a combined settling and separating operation in which the insoluble portion of the gluten mixture is continually removed by a raking mecha-

nism.) The corn gluten is then resettled and filter pressed (Fig. 81), usually as a mixture with the fine fiber which was removed by the shakers.

In addition to the oil cake meal and the gluten, other feed by-products are recovered, namely: the corn solubles present in the steep water, the corn hulls (or bran), and the fine fiber which were removed by the reels and shakers from the wet mash produced by the buhr mills. According to Sair and Fetzer,¹¹ the end products obtained per bushel (56 lbs.) of corn are approximately as follows: water, 8.4 lbs.; starch, 33.0 lbs.; oil, 1.5 lbs.; corn oil meal, 1.8 lbs.; hull or bran, 2.0 lbs.; fine fiber or "No. 17 tailings," 2.3 lbs.; gluten, 3.5 lbs.; and steep water solids, 3.5 lbs.



Fig. 81.—A gluten press. The pressed gluten is pried free and drops to a conveyor belt below.

The various feed by-products are merchandised in the form of three livestock feeds: corn oil meal, gluten meal, and gluten feed. As already indicated, corn oil meal is simply ground expeller cake; gluten meal usually comprises corn gluten mixed with fine fiber, although it may sometimes contain part of the steep water solids; and gluten feed contains the coarse hull or bran, steep water solids, and sufficient gluten to bring the protein content of the mixture up to a guaranteed minimum level.

(c) Yields

According to Bartling,¹⁰ corn containing 16% moisture (47 lbs. dry matter per bushel) is resolved into the following main products when subjected to the wet-milling process: starch, 66%; feeds, 29.8%; and oil, 3.2%; with a loss of 1.0%.

IV. OATS

Milling

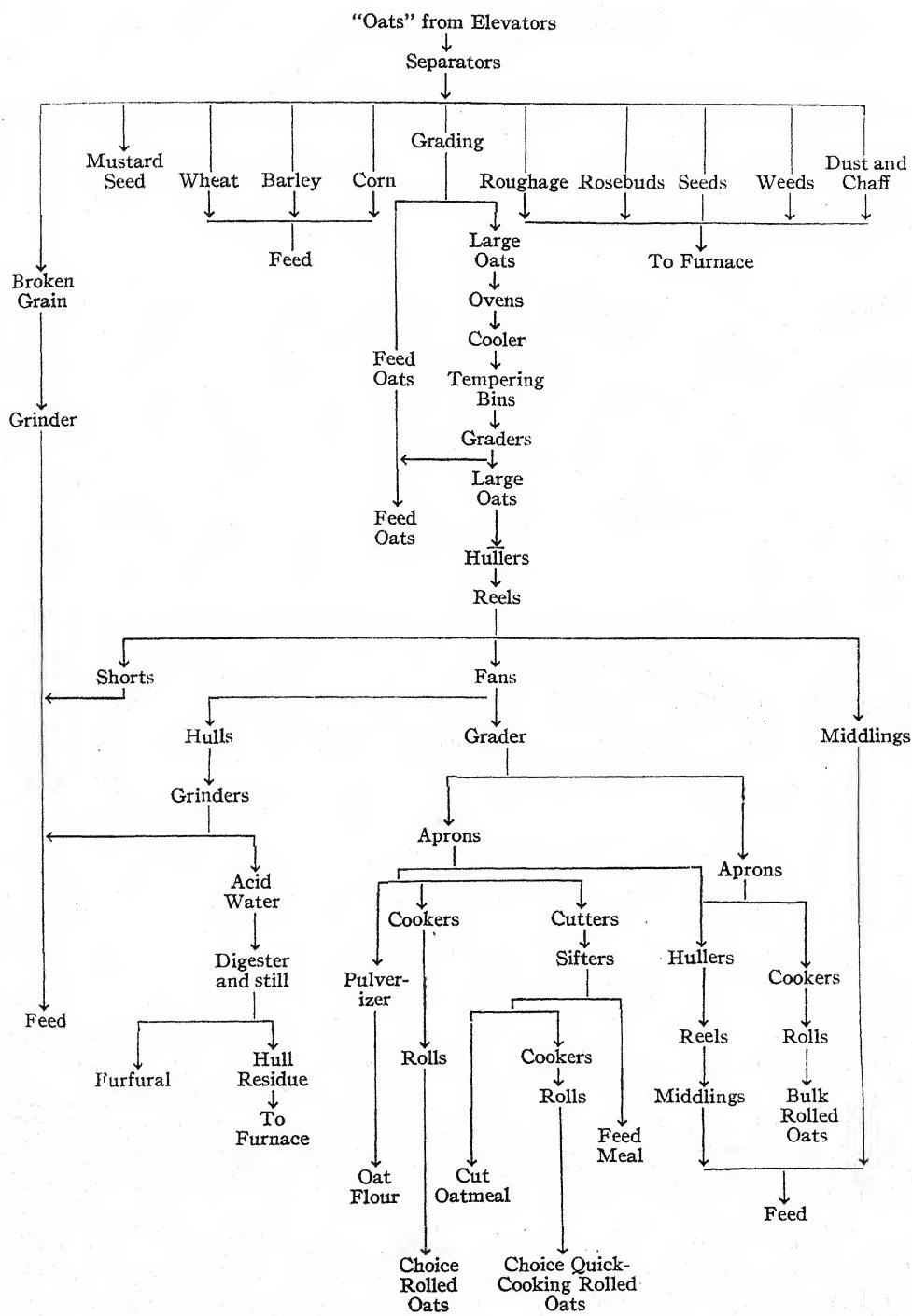
For milling purposes, plumpness, soundness, and freedom from heat damage, foreign odors, wild onion seed, smut, must, and molds are important, and only oats of high grade (No. 1 and No. 2) are employed. The milling machinery in each producing area is adapted to mill efficiently oats of the highest test weight which are continuously available. In the North Central States, white and yellow oats are milled; but, as red varieties are the class principally grown in the South Central States, red oats are milled in this area. The groat of red oats is similar in color to that of other classes. In the milling of oats, essentially the fibrous hull and adhering portions are removed, and the bulk of the bran, the aleurone layer, and the germ, which are rich in protein, vitamins, and minerals, remain with the portion which is used as human food. Hence, rolled oats and oatmeal, like brown rice, are whole-grain cereal products from the nutritive standpoint. The outline of the oat milling process which follows is based largely on the description given by Brownlee and Gunderson.¹² The most important steps in the processing of oats are indicated in the flowsheet given in Fig. 82.

The initial step in the oat-milling process involves thorough cleaning of the oats to remove extraneous matter, such as other cereal grains, weed seeds, chaff, etc., and to separate the light oats; in this cleaning and sizing operation some thirty different machines or separators, which serve specific purposes, are employed. The milling oats from the cleaning operations are conveyed to the dry house, where the moisture content is reduced from about 10 or 12% to about 6% in order to increase the brittleness of the hulls and thereby facilitate their removal in the later operation of hulling; the drying or slow roasting process to which the oats are subjected also serves to develop a desirable flavor in the groats. The oats are usually dried or roasted in a vertical stack of large steel pans, as diagrammatically represented in Fig. 83. The oats are fed to the center of the top pan and are kept in motion by a sweeping paddle which gradually moves them toward a spout which carries them to the middle of the next lower pan. In this drying operation, the oats are maintained at about 180° F. for approximately one hour. The oats from the bottom of the roasting stack are conveyed through an air cooler to storage or tempering bins.

(a) Description of Process

The milling process proper comprises the following principal steps: grading or sizing; hulling; separating the hulls and unhulled oats from the groats; steaming the groats; rolling the groats into flakes; and packaging. The parched oats from the storage bins are passed through graders which sort them into 5 or 6 groups known as large oats, slim oats, long slims, No. 1 stub, No. 2 stub, and No. 3 stub, according to length. Each of these streams is sent to separate hulling stones, the groats from the large oats yielding the choicest grade of rolled oats. The hullers (see Fig. 84) are

¹² H. J. Brownlee and F. L. Gunderson, *Cereal Chem.*, 15, 257 (1938).

Fig. 82.—Oatmill flowsheet.¹²

similar to the machines employed in hulling rough rice and consist of two "stones," the lower one of which is flat and stationary, while the upper one is slightly conical and rotates rapidly. The space between the stones is carefully adjusted so that it is less than the length of the grain, but slightly greater than the length of the groat. As the oats are carried from the center to the periphery of the stones, they are turned endwise; the pressure exerted on the ends of the grain shatters the hull and releases the groat. The careful grading of the oats as to length is essential in minimizing the breakage of the groats and the production of flour.

From the hulling stones, the mixture of unhulled oats, hulls, whole and broken groats, and flour, is first passed through a horizontal sifting reel to remove oat flour

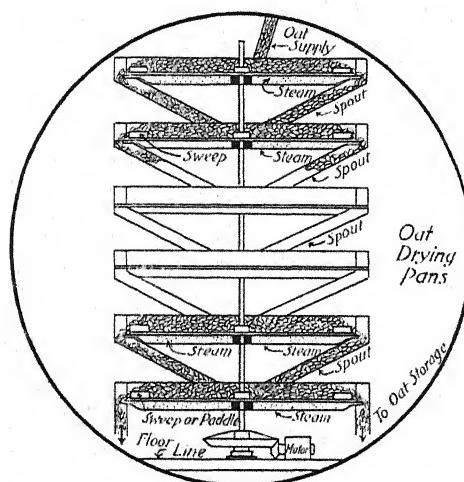


Fig. 83.—Diagrammatic representation of oat drying pans. (Figs. 83-86 courtesy H. J. Brownlee, The Quaker Oats Company, Cedar Rapids, Ia.)

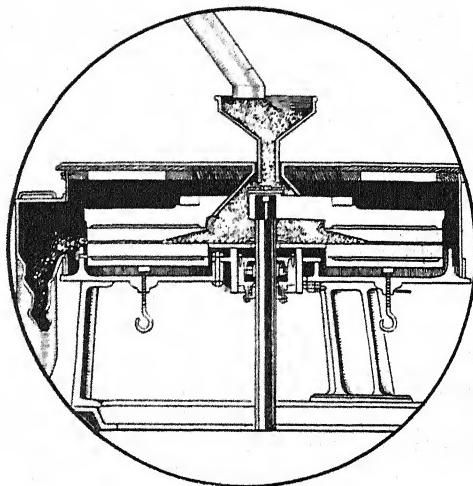


Fig. 84.—Diagrammatic representation of an oat huller.

and then through a succession of air separators to take out the hulls. The remaining mixture of unhulled oats and groats is graded to take out broken groats, and then is passed through a series of apron machines. Apron machines (Fig. 85) are provided with pockets of the correct size to receive the groats and carry them over the top of the machine while the unhulled oats slide off the apron at the bottom.

The groats thus obtained may now be further processed in a number of ways depending upon the product desired. In the hulling and subsequent processes, the fuzzy material (oat shorts) and small fragments of the groats (oat middlings) are removed.

In the manufacture of the standard type of slower cooking choice rolled oats, the whole groats are steamed directly with live steam at atmospheric pressure. This treatment sterilizes and partially cooks the groat; it also increases the moisture content, which is essential to avoid excessive production of fine particles or flour in the subsequent rolling process. If, on the other hand, the so-called quick-cooking rolled

oats are desired, the groats are steel-cut, by means of rotary-type cutters, into pieces of varying size, often classified as A (fine), B (medium), and C (coarse) steel-cut oats. Before rolled oats became prominent, steel-cut or Scotch oats were the chief form in which oats were consumed as human food. The B or medium steel-cut oats are the size normally employed in the production of quick-cooking rolled oats; each fragment represents about one-third of a groat and makes one flake. After cutting, the groats are heat treated in the same manner as the whole groats used in the production of large flakes of standard rolled oats; the broken groats employed in the manufacture of bulk rolled oats are also steamed in the same manner.

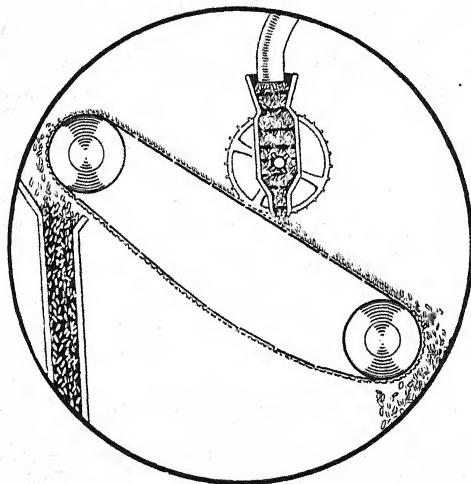


Fig. 85.—Diagrammatic representation of an apron machine for the separation of unhulled oats and groats.

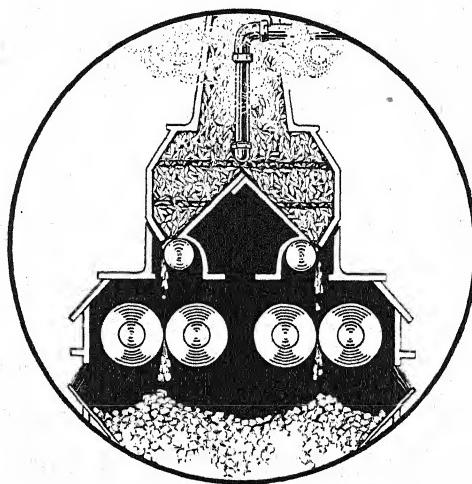


Fig. 86.—Diagram of rolls used for the manufacture of rolled oats.

The final step in the manufacturing process is the flaking process accomplished by feeding the steamed groats between two large steel rolls, as depicted in Fig. 86. In the production of quick-cooking rolled oats, the rolls are adjusted to produce a thinner flake than that of the standard slower cooking type. As the heat treatment of the groats for the two types of rolled oats is similar, the quicker cooking properties are attained by decreasing the size and thickness of the flake.

For livestock feeding purposes, *clipped oats* are frequently manufactured. The oats are put through a machine which clips off the ends of the hulls, thereby increasing the test weight and lowering the fiber content.

(b) Yields

The milling yield of rolled oats depends upon a number of factors such as the plumpness, cleanliness, and moisture content of the grain and the skill with which the various

machines are operated. According to Brownlee and Gunderson,¹² 13.5 bu. of medium quality No. 2 white oats will yield 1 bbl. (180 lbs.) good-quality rolled oats; this corresponds to a yield of 41.7%. As about 30% hulls are produced, this leaves a balance of 28.3% of other products, including oat shorts and oat middlings, cereal grains, weed seeds, and other material removed from the oats in the cleaning process.

V. RICE

Milling

The objective of rice milling is the removal of hull, bran, and germ with a minimum breakage of the endosperm. Wise and Boomei,¹³ Reed and Liepsner,¹⁴ Fraps,¹⁵ and, more recently, Wayne¹⁶ have described the commercial milling of rice as carried out in the United States. The process is diagrammatically illustrated in Fig. 87.

(a) Description of Process

The mills are located in the rice producing areas and the rough rice is received in sacks containing from 175 to 230 lbs. each; it is bought on the basis of a "barrel" of 162 lbs. It is thoroughly cleaned by passing it successively through a scalper, clipper, and monitor (aspirator) and is then conveyed to the shelling stones which loosen the hulls. The shelling stones are somewhat similar to the buhrstones formerly used in wheat milling. The top stone revolves and is set the proper distance above the lower stationary stone to permit the rice grains to assume a somewhat vertical position. The hulls are split open by the pressure exerted on the ends of the grains, thereby releasing the kernels. As the grains are not uniform in length, the stones are adjusted to hull the longer grains without undue breakage, and, normally, 15 to 20% of the rough rice remains unhulled. In some mills, the shelling stones consist of two steel disks coated with Carborundum. The lower disk revolves and, when the rice reaches the periphery, it is automatically cleared from the machine by centrifugal force.

The mixture of loose hulls, some true bran and germ, and hulled and unhulled kernels is then passed through a "stone reel," consisting of a large, revolving, octagonal framework covered with wire screens, where fine material, known as stone-reel bran, is removed. The large pieces of hull, which remain, are next removed by suction in a monitor. The stream coming from this machine comprises a mixture of hulled and unhulled grains which are separated in an ingenious device known as a paddy machine. This consists of a large box shaker fitted with vertical metallic plates set on an incline to form zigzag ducts. These plates and the shaking action cause the less dense, unhulled rice, or paddy grains, to move gradually upward, while the heavier, hulled grains move downward and are collected at the lower or "clean side" of the machine.

¹³ F. B. Wise and A. W. Boomei, U. S. Dept. Agr., *Bull.* 330 (1916).

¹⁴ J. B. Reed and F. W. Liepsner, U. S. Dept. Agr., *Bull.* 570 (1917).

¹⁵ G. S. Fraps, Texas Agr. Expt. Sta., *Bull.* 191 (1916).

¹⁶ T. B. Wayne, *Food Industries*, 2, 492 (1930).

The grain, with the hulls removed but with most of the bran and germ intact, is called brown rice. The unhulled grain from the upper or "rough side" of the paddy machine is conveyed to auxiliary or second shelling stones, which are set to smaller clearances than the first stones; the grain then re-enters the main stream going to the stone reel.

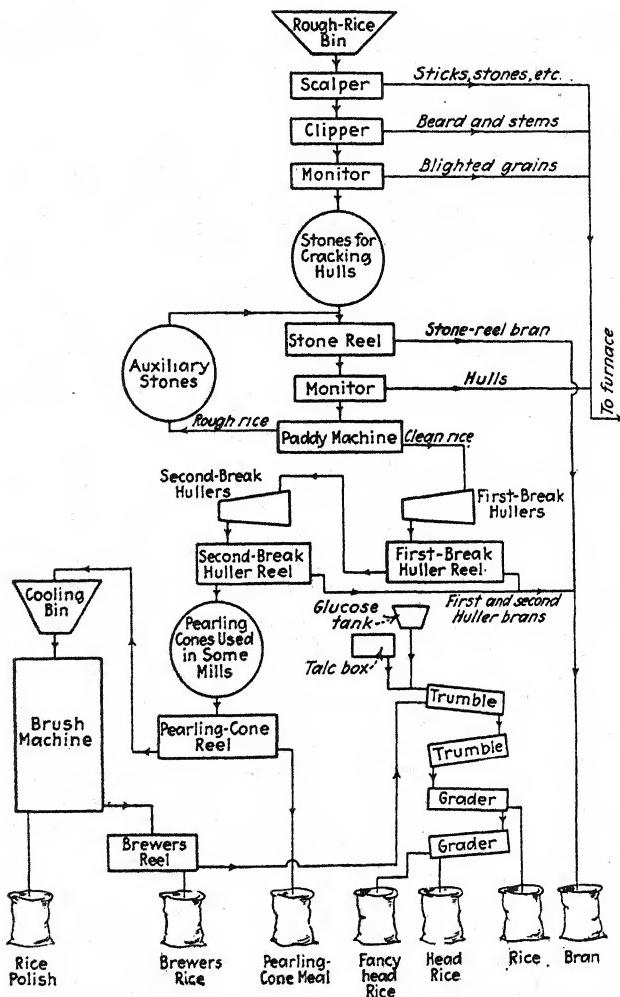


Fig. 87.—Diagram illustrating the various steps in the milling of rice. (From U. S. Dept. Agr. Bull. 570 (1917).)

The brown rice from the clean side of the paddy machine is sent to machines erroneously called hullers, since their function is to remove the bran layers, and the germ, from the hulled grain. The huller consists essentially of a grooved, tapering cylinder which rapidly revolves within a concentric hollow cylinder which is so spaced

as to cause minimum breakage of the grain. As the kernels are forced through the cylinder, the outside bran layers and most of the germ are removed by the scouring action between the rough inside walls of the tapering cylinder and the grooved surface of the revolving inner core.

After leaving the first huller, the bran is removed in a bran reel and the partially refined rice sent to the second-break huller; the stream from this apparatus again passes through a reel, which separates the second-break bran. In some rice mills, pearlizing cones are used instead of, or to supplement the work of, the hullers. These are similar to the machines used in the pearlizing of barley, and consist essentially of the frustum of a cone coated with Carborundum and which revolves inside a heavy screen wire. The rice is fed from the top, being scoured by friction as it passes downward between the revolving cone and its surrounding sieve (mantel). The severity of the scouring is varied by raising or lowering the cone, thereby changing its distance from the wire screen. The pearlizing cone is said to be less severe in its action than the huller and to cause less kernel breakage.

The partially scoured rice from the last bran reel passes to a cooling bin and from there to the brush machine for finishing. This scouring machine consists of a large vertical cylinder, dressed with overlapping soft leather strips, which revolves at high speed within an outer stationary cylinder of wire screen. As the rice passes downward, it is polished between the leather strips and the screen wire; the heat produced in the brush is removed by an upward moving stream of air. In the brush any residual bran and germ, the aleurone layer, and some of the starchy endosperm are removed. The mixture of fine material which passes through the screen of the brush and that removed by dust collectors from the air stream is known as rice polish.

The polished rice, as it comes from the brush, contains whole endosperms and broken particles of various sizes. The smallest particles, or brewers' rice, are removed in a reel covered with a 10-mesh screen, known as the brewer's reel. Milled rice from which only the brewers' rice has been removed is referred to as line rice, straight rice, or straight-run rice. If the rice is not to be coated, it is then passed through grading reels and indented cylinders or disks which grade or size the rice into head rice (consisting mainly of whole endosperms), second head rice (consisting of the larger broken particles and some whole kernels), and screenings rice (consisting of the more finely broken fragments).

When the rice is to be coated to make it whiter and more lustrous, it goes directly from the brewer's reel to the coating trumbles before it is sized. The coating trumbles are large, slightly inclined revolving cylinders fitted with baffles running lengthwise. As the rice traverses the cylinder, it receives a coating amounting to about 0.2% glucose and 0.08% talc. Coated rice must be so labeled, and directions for the removal of the coating material must be printed on the containers.

(b) Yields

The average percentage yields of the various products obtained from rough rice as compiled from data given by Fraps¹⁵ are shown in Table 36.

TABLE 36

AVERAGE PERCENTAGE YIELDS OF THE VARIOUS PRODUCTS OBTAINED IN MILLING RICE^a

Rice type	Fancy rice, %	Second head rice, %	Screenings rice, %	Brewers' rice, %	Rice bran, %	Rice polish, %	Rice hulls, %
Long-grain, Honduras	38.0	12.0	11.4	4.4	9.5	3.2	21.5
Medium-grain, Blue Rose	59.3	3.2	5.7	2.5	8.3	2.5	18.5
Short-grain, Japan	58.6	3.1	5.6	3.1	8.6	3.1	17.9

^a Compiled from data given by Fraps.¹⁶

The milling quality of rough rice is determined by the yield of head rice obtainable. Jones *et al.*¹⁷ have pointed out that milling quality is a function of type, variety, and environmental conditions. In confirmation of the earlier work of Fraps, they report that, on the average, the short-grain varieties give somewhat higher yields than the medium-grain varieties; while as a group the long-grain varieties give the lowest yields of head and of total rice.

VI. RYE

Rye is milled to flour by a process similar to that described for wheat; but, because the bran adheres tenaciously to the endosperm, it is not practical to make clean "middlings" or to purify them by aspiration. Moreover, rye is a "tough" grain. The middlings are not so friable as those of wheat, and, if ground between smooth rolls, tend to flake or flatten rather than pulverize. Accordingly, the reduction rolls are finely corrugated (40 to 50 corrugations per inch). Since little advantage is to be gained by the production of middlings, the objective in milling is to produce flour during the breaking process. The break rolls are set relatively close together and have somewhat finer corrugations than those used for the corresponding breaks in the instance of wheat. Thus, the first break rolls commonly have 16 corrugations per inch. The breaking system involves 5 to 7 breaks; and, commonly, 25 to 30% of the first break chop consists of flour. After each break, the chop goes to the bolter where it is separated into flour, middlings, and tailings. The tailings go to the next break rolls, while the middlings are reduced to flour by finely corrugated rolls.

The highest grade of flour is produced by the first break rolls. As the purity of the flour decreases, it becomes darker in color and has a more pronounced rye flavor. In American milling practice, three main grades of rye flour are produced: "white" or "light"; "medium"; and "dark." The white, or light, rye flour is commonly called "patent," and represents 50 to 65% of the wheat. "Medium" rye flour corresponds to "straight-grade" wheat flour, while "dark rye flour" corresponds to the "clears," that is, the dark flour represents that portion of the total flour which remains after the white or patent rye flour is taken off. In addition to these three main grades, "cut" and "stuffed" straights are sometimes produced; the former is a "medium"

¹⁷ J. W. Jones *et al.*, U. S. Dept. Agr., *Circ.* 612 (1941).

rye flour from which a small percentage of white rye flour has been taken out, whereas a "stuffed straight" is a "medium" rye flour to which a small percentage of "dark" has been added. For the baking of "pumpernickel" rye bread, rye millers produce a coarse unbolted rye meal, known as pumpernickel flour.

The milling of rye normally yields 65% light or patent rye flour, 15 to 20% dark rye flour, and 15 to 20% offals.

VII. WHEAT

1. The Roller Milling Process

During the course of many centuries, flour milling has progressed from a laborious household task to a vast industry which is vitally essential to our modern civilization. The milling of grain as food for man has been traced back over 8000 years. It is probable that a crude flour mill was one of the earliest mechanical devices extensively employed by man. The first actual grinding mill was the saddle stone employed by the Babylonians, Assyrians, and Egyptians. The saddle stone, so named because of its shape, was a concave stone in the hollow of which the grain was crushed by a semicylindrical upper stone. This was followed by the mortar and pestle, which permitted the pounding of the grain, and later by the quern, a Roman invention. In the latter device, the upper stone was rotated, and wheat fed through a hole in the center was crushed between the grooved grinding faces of the upper and lower stones. It is known that the Romans bolted their meal and produced several grades of flour. The quern was eventually developed into the large millstones employed in commercial milling until the invention of the steel roller mill, in 1820, by Helfenberger in Switzerland. In 1810, a Hungarian, Paur, patented the first crude purifier, a machine for classifying the middlings according to size and removing light branny material by means of air currents. The purifier marked the introduction of "high grinding," by which the wheat was gradually reduced to flour and the fragments bolted and purified after each grinding. The introduction of the purifier in Minneapolis, in 1870, followed by the adaptation of the Hungarian "long system" of roller milling and the discovery that the bran could be more effectively separated if the wheat was moistened, or tempered, made Minneapolis famous as a milling center.

It is possible here only to outline the fundamental principles and procedures employed in the modern roller milling process of flour production; the reader is referred to such works as Amos,¹⁸ Dedrick,¹⁹ Kozmin,²⁰ and Miller,²¹ for a more extensive treatment. In the manufacture of white flour, the aim is separation of the endosperm of the grain from the bran and germ followed by pulverizing it to very small particles. A partial mechanical separation of these closely adhering structures is possible because of differences in their physical properties. Because of its high fiber content, the

¹⁸ P. A. Amos, *Flour Manufacture*. Longmans, Green, New York, 1925.

¹⁹ B. W. Dedrick, *Practical Flour Milling*. National Miller, Chicago, 1924.

²⁰ P. A. Kozmin, *Flour Milling*. Routledge & Sons, London, 1917.

²¹ E. S. Miller, *Studies in Practical Milling*. Miller Pub. Co., Minneapolis, 1941.

ROLLER MILLING PROCESS OF WHEAT

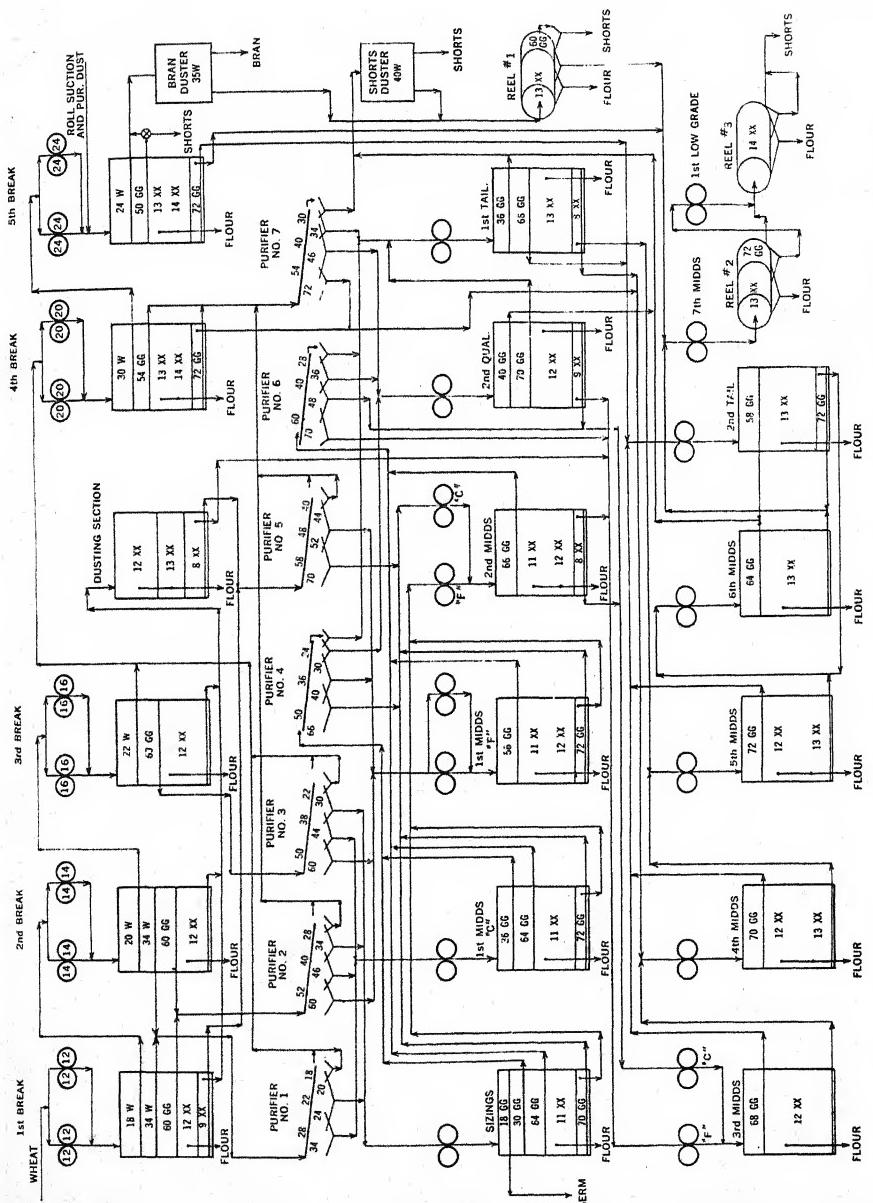


Fig. 88.—Flowsheet for a flour mill with a capacity of approximately 500 barrels flour per day. (Redrawn from a flowsheet given by E. S. Miller in "Studies in Practical Milling," courtesy of The Miller Publishing Co., Minneapolis, Minn., 1941.)

bran is tough, while the starchy endosperm is friable; and the germ, because of its high oil content, readily flakes when passed between smooth rolls. These structures also differ in density, a fact which makes it possible to utilize air currents to advantage. The differences in the friability of the bran and endosperm are accentuated by a

process known as tempering or conditioning which consists in adding water several hours before the wheat goes to the rolls in order to toughen the bran. The milling process proper comprises a gradual reduction in particle size, first between corrugated or break rolls, and, later in the process, between smooth or reduction rolls. The separation is not quantitative, however: some of the endosperm is lost in the offals; and appreciable quantities of bran and germ are present in certain of the flour streams. These variations in purity give rise to different grades of flour.

(a) *Description of Process*

The various steps involved in wheat flour production are wheat selection and blending, cleaning, conditioning or tempering, breaking, bolting or sieving, purification, reduction and bleaching. To these must be added flour "diastating" where necessary, as well as vitamin and mineral enrichment when enriched flours are being produced. A wheat mill flowsheet is shown in Fig. 88.

Wheat Selection and Blending.—The chemical composition and quality of individual lots of wheat vary widely, depending upon the variety and environmental conditions under which they are grown. Since the miller must produce a flour of definite characteristics for the particular market he is serving and endeavor to maintain uniform quality from day to day, month to month, and year to year, the selection of the wheats he purchases and the binning of them according to quality are essential phases of modern milling. With an adequate supply of wheat, sorted according to quality characteristics, the miller is in a position to blend these or "build a mill mix" which will be uniform over long periods. Each new crop brings special problems; and the large mill organizations make a survey of the milling and baking qualities of wheats collected from the various producing areas soon after harvest. The results aid the millers in mapping the areas from which desirable wheat for their purposes may be obtained, and to resort in part to "geography buying" when the wheat reaches the terminal markets.

Cleaning.—Commercial wheat as received at the mills contains various impurities, such as stinking smut, weed seeds, other cereal grains, soil, etc. Many special machines have been developed for removing the various types of impurities. The preliminary cleaning involves the use of sieves, air blasts, and disk separators. This is followed by dry "scouring." In the scourer, the wheat is forced against a perforated iron casing by beaters fixed to a rapidly revolving drum. This severe treatment removes foreign material lodged in the creases of the kernels as well as the brush hairs. Many American mills are equipped with wheat washers (Fig. 89) in which the wheat is scrubbed under a flowing stream of water. The washed wheat is passed through a "whizzer" (centrifuge) which removes the bulk of the liquid water.

Conditioning or Tempering.—The conditioning or tempering process immediately follows the final cleaning; and, when wheat is washed, part of the water required for tempering is added in the washers. In tempering, a suitable addition of water is

made and the wheat allowed to stand for a sufficient length of time to secure maximum toughening of the bran with optimum mellowing of the endosperm. Both the quantity of water added and the tempering time must be varied with different wheats to bring the grain to the optimum condition for milling. In fact, the success of the subsequent milling operations depends, in no small measure, on the proper tempering

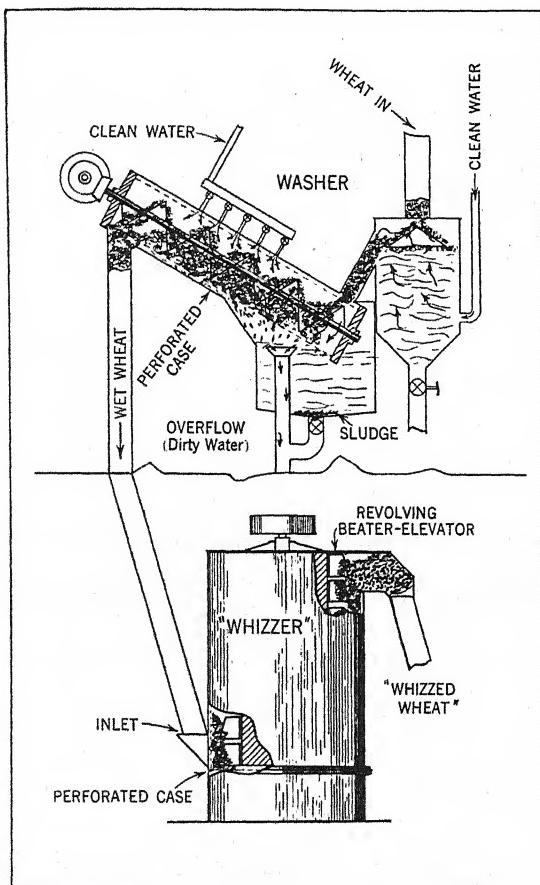


Fig. 89.—Diagram of a wheat washer and whizzer.
(From "For Millers in the Making," courtesy The Miller Publishing Co., Minneapolis, Minn.)

of the wheat. If the bran is not properly "toughened" it tends to become pulverized along with the endosperm particles. On the other hand, if excess moisture or too long a tempering period is employed, the endosperm tends to flake rather than to become pulverized between the smooth rolls, and thus to be lost in the offals. The quantity of water added is augmented with decreasing moisture content, increasing vitreous-

ness, and increasing plumpness of the wheat. Normally, hard wheat after tempering contains 15 to 16% moisture.

Heat is frequently used as an adjunct to tempering to accelerate the process. In American milling practice, the use of heat is normally confined to temperatures which do not induce changes in the physical properties of the endosperm proteins.

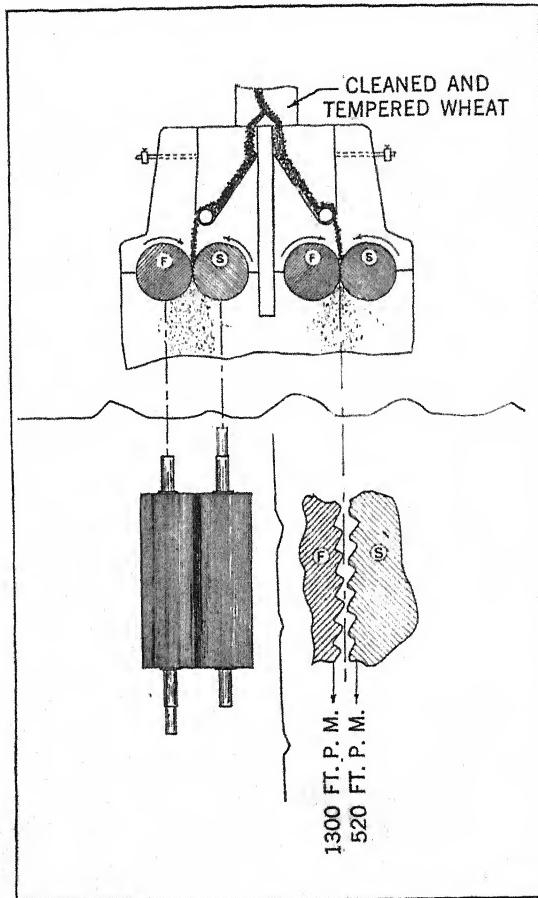


Fig. 90.—Diagram of a stand of break rolls. (From "For Millers in the Making," courtesy The Miller Publishing Co., Minneapolis, Minn.)

In Europe, hot conditioning at relatively high temperatures and to higher moisture contents (16–18.5%) is employed. Since 1940, continuous short-time conditioners have been engineered in America and are being used in some mills. In these devices, the wheat first passes through a hot conditioning chamber where part of the moisture is added as steam, then through a second tempering chamber where sufficient

warm water is added to produce an excess moisture content; the wheat finally passes through a third chamber where surface moisture is removed by evaporation, thereby cooling the grain. The wheat is said to be ready for the mill after one to two hours of standing, so that any necessary adjustments can be made much sooner than with the conventional method.

In the customary tempering method, the wheat is again scoured after it has been held in the tempering bins for some hours, and a second small addition of water to raise the moisture content by a further 0.5% is sometimes made from 20 min. to 1 hr. before the wheat goes to the rolls.

Breaking.—The first part of the grinding process is carried out on corrugated rolls, known as break rolls, which are usually 24 to 30 in. long and 9 in. in diameter, and are operated in opposite directions at a differential in speed of about $2\frac{1}{2} : 1$; each stand has 2 pairs of rolls (see Fig. 90). In the first break rolls, the corrugations are usually 10 to 12 to the inch, this number increasing, in progressing through the break system, to as high as 26–28 corrugations to the inch on the fifth break roll. The corrugations run the length of the roll but, instead of being cut parallel with the edge, are given a spiral, which is augmented with an increase in the number of corrugations. As the rolls turn rapidly toward each other, the edges of the corrugations of the fast roll cut across those of the slow roll, so that there is a shearing, as well as a crushing, action on the wheat which falls in a rapid stream between them. The first break rolls are spaced some distance apart so that the wheat is only lightly crushed and only a small quantity of fine material or flour is produced. After sifting or bolting, as described below, the coarsest material is conveyed to the second break rolls, which are set a little closer together than the first break rolls, so that the material is crushed a little finer and fragments of endosperm are released. The crushed stock is sifted and the coarsest material passed through the third break rolls, and the stock again sifted. This process of alternately grinding and sifting is repeated until 4, 5, or 6 breaks have been given. At each successive break, the rolls are set a little closer together so that more and more endosperm is released and removed by sifting. The material going to each succeeding break contains less and less endosperm; and after the fifth or sixth break the largest fragments consist of flakes of outer covering of the wheat. The latter is passed through a special machine (called a bran duster) which removes a small quantity of low-grade flour, and is then packed as bran.

Bolting or Sieving.—After each grinding on the break rolls, the crushed material, called stock or chop, is conveyed to a sifter or bolter. The sifter or bolter is, essentially, a large box fitted with a series of sloping sieves. The break sifters have a relatively coarse wire sieve at the top and progressively finer silk sieves arranged below, ending with a fine flour-silk at the bottom. The sifter is given a gyratory motion so that the finer particles of stock pass through the sieves in moving from the top (head) to the bottom (tail). The particles which are too coarse to pass through any particular sieve tail over it and are at once removed from the sifter box. In this manner three general classes of material are separated: coarse fragments which are fed to the next succeeding break until only bran remains; fine particles, or

flour (first break flour, second break flour, etc.), which pass through the finest or flour sieve; and granular particles of intermediate size which are called middlings. These middlings are a quite different wheat product from the cattle feed known as middlings.

Purification.—The middlings consist of fragments of endosperm, mixed with small pieces of bran and the released embryos. Several sizes of middlings are separated from each of the break chops; and individual streams of similar size and degree of refinement resulting from the bolting of different break chops are combined. The

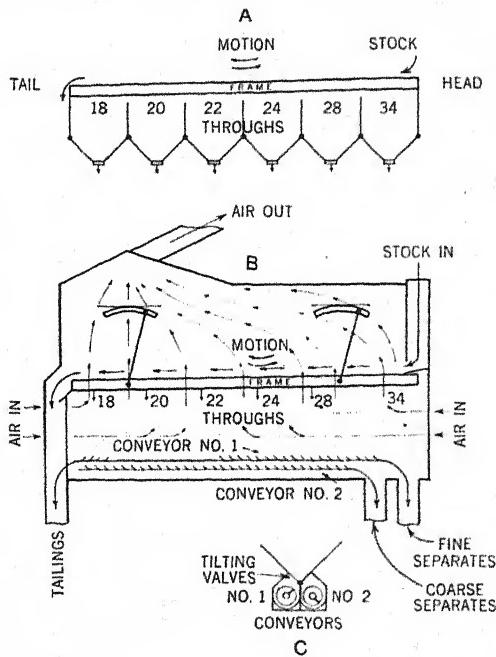


Fig. 91.—Diagram illustrating the principles of the middlings purifier. (Reproduced from E. S. Miller, "Studies in Practical Milling," courtesy The Miller Publishing Co., Minneapolis, Minn., 1941.)

next step is to remove, as far as possible, the branny material from the graded middlings. This is accomplished in machines known as purifiers which, in addition, produce a further classification of the middlings according to size, and hence complete the work of the sifters. In the purifier, the principle of which is illustrated in Fig. 91, the shallow stream of middlings is made to travel over a large sieve which is rapidly shaken backwards and forwards. The sieve consists of tightly stretched bolting silk, or grits gauze, the openings through which become progressively coarser in proceeding from the head to the tail end of the machine. An upward current of air moving through the sieve draws off very light material to dust collectors, and

tends to hold branny particles on the surface of the moving middlings so that they drift over the tail of the sieve.

Another method of classifying middlings based on differences in density is effected by the use of a machine called a purograder.

Reduction.—The purified and classified middlings are gradually ground to flour between smooth rolls, called reduction rolls, which revolve at a differential of about $1\frac{1}{2}:1$. The space between the rolls is carefully adjusted to suit the granulation of the middlings; and, as the endosperm fragments pass through the rolls, they are subjected to a crushing and rubbing action which reduces them to finer middlings and flour, while any remaining fibrous fragments of bran tend to be flaked or flattened. After each reduction, the resulting chop is bolted through its own sifter, as in the instance of the break stock. Most of the bran fragments are removed on the top sieve, while flour passes through the finest or bottom sieve. The remaining middlings are classified according to size by the intermediate sieves and go to their respective purifiers and thence to other reduction rolls. These steps are repeated until most of the endosperm has been converted to flour and most of the bran chips have been removed as offal by the reduction sifters. All that remains is an intimate mixture of very fine middlings and bran with a little germ, that is, feed middlings.

The embryos are largely released by the break system and appear as lemon-yellow particles in certain of the coarser middlings streams, known as sizings. In the course of the reduction of the sizings, the embryos are flattened out and are separated as flakes upon bolting the chop. At one time, all the germ thus obtained was mixed with the shorts but now, on account of its richness in certain vitamins, it is finding some special uses.

Germ may also be separated without reduction of the sizings by means of gravity and the use of regulated air currents.

(b) *Flour Grades*

Each grinding and bolting operation results in a stream of flour; in addition to the various break (first, second, third, etc.) and middlings flours (first, second, third, etc.), a small quantity of flour originates from special units such as dust collectors, bran and shorts dusters, and the like. Each of these flour streams has its individual characteristics and properties as indicated by the data given in Table 136 on page 655, Volume I. The first middlings separation is the most highly refined. With each successive reduction, the flour contains more and more pulverized bran and germ. The flour from the last reduction, commonly called red dog, is dark in color and high in components characteristic of the bran and germ, such as protein, ash, fiber, pentosans, lipids, sucrose, and vitamins. Such flour bakes into inferior, dark colored, coarse grained bread, and is generally sold as feed flour.

The differences in the chemical composition of the various flour streams are not due solely to variations in their content of bran and germ: it has been shown, for example, that the protein content of the endosperm steadily decreases in progressing from the outer to the central zone of the endosperm, so that the protein content of a

flour will be determined, in part by the region of the endosperm from which the flour particles were derived.²²

In a large mill, there may be 30 or more streams of varying composition and purity which must be collected and merchandised as flour. The various flour streams may obviously be grouped together in a number of ways. If all the flour streams are combined, the resulting flour is called straight flour. Frequently the more highly refined streams are taken off and sold separately as patent flours, while the remaining streams which contain more bran and germ are known as clear flours. The percentage of the total flour merchandised as patent flour varies widely, and the more streams of successively decreasing refinement which are included in the patent flour, the lower the "quality" of the remaining, or clear flours, becomes. In the instance of bread-wheat flours, the various patents and approximate percentages of the total flour they represent are as follows: family patent, 70-75%; short patent, 75-80%; medium patent, 80-85%; and long or standard patent, 90-95%. The residual or clear flours are sold as fancy clear, first clear, and second clear, in order of decreasing degree of refinement. Two additional grades of flour, cut straight and stuffed straight, are sometimes produced: a cut straight results when a small percentage of the most highly refined flour is taken off, while a stuffed straight is a straight grade flour to which some clear or low-grade flour has been added.

The clear flours are too dark in color and of too low a baking quality to make acceptable white bread; some of the better clear flours are used in mixtures with rye flour, and the lower grades are used in the manufacture of such products as dog biscuits. Wheat flour is sifted through fine silk bolting cloth which never has less than 110 meshes to the linear inch. The blended flours are always rebolted before packing. For this purpose a centrifugal reel is employed.

2. Flour Bleaching and Maturing

Wheat flour, in its natural, freshly milled state, contains very small quantities of yellow pigments which impart a definite creamy to yellow hue to the flour. The concentration of these pigments varies from about 1.8-3.8 p. p. m., depending upon the nature of the wheat and the grade of flour. In general, hard red winter wheat flours contain more of these pigments than hard red spring wheat flours. Wheats which have been improperly filled as a result of wheat stem rust yield flours of high pigment content. The lower the grade of flour milled from a given wheat mix, the higher is the pigment content of the flour.²³

When unbleached freshly milled flour is stored, it slowly improves in color;²⁴ also, when flours undergo natural aging, other incompletely understood changes occur which result in a gradual improvement in baking quality. Before the introduction of bleaching and maturing agents, new crop flour frequently had to be stored for some

²² N. A. Cobb, N. S. W. Dept. Agr., *Misc. Publ.*, 539 (1905).

²³ C. G. Ferrari, *Cereal Chem.*, 6, 347 (1929).

²⁴ C. G. Ferrari and C. H. Bailey, *Cereal Chem.*, 6, 457 (1929).

months, preferably at a moderate temperature, in order to allow these changes to take place. In modern practice, the costs of storage and the hazards from spoilage and insect infestation are lessened through the use of very small quantities of oxidizing agents such as nitrogen peroxide, chlorine, nitrosyl chloride, nitrogen trichloride, and benzoyl peroxide. Nitrogen peroxide and benzoyl peroxide bleach the yellow pigments but have no measurable maturing effect at the dosages normally employed by the miller; that is, they do not modify the baking properties of the flour. Chlorine, nitrosyl chloride, and nitrogen trichloride, on the other hand, have both a bleaching and maturing action. The miller therefore has means at his disposal for controlling the bleaching and maturing of his flour independently.

Historically, nitrogen peroxide was the first reagent to come into general use. In 1903, James Alsop patented a convenient method of generating this gas from oxygen and nitrogen of the air by means of a flaming electric arc. Chlorine has been widely used. One flour-treating process has involved the use of liquid chlorine containing 0.5% nitrosyl chloride; this mixture, known as "Beta-Chlora" was patented in 1914. Nitrogen trichloride, introduced by J. C. Baker in 1921, is in general use in bleaching bread flours; it is merchandised under the trade name of "Agene." Nitrogen trichloride is generated in the mill by means of the reaction between chlorine and aqueous solutions of ammonium salts, such as ammonium sulfate. Like nitrogen peroxide and chlorine, it is highly diluted with air before it enters the flour agitator; its bleaching and maturing actions are practically instantaneous. The dosage of Agene depends upon a number of factors such as the characteristics of the wheat, the flour grade, and the length of time the flour is likely to remain in storage before baking.

Hard red spring wheats yield flours of lower yellow pigment content and requiring less maturation than those from hard red winter wheats—as the grade of flour decreases, the more the maturation required. Patent spring wheat flours are normally treated with from 0.75 to 1.5 g. of Agene per bbl., while the dosage for patent winter wheat flours varies from about 1.5–3.0 g. per bbl. and for clear flours, from 3–6 g. per bbl.

Benzoyl peroxide, unlike the other bleaching agents mentioned above, is a crystalline solid; it was patented as a flour bleaching agent in 1925. Since benzoyl peroxide, in the pure form, tends to be spontaneously inflammable, and since minute quantities are required to bleach flour, one part of the finely divided reagent is mixed with about 6 parts of a carrier consisting of either potassium alum and magnesium carbonate, or a mixture of calcium sulfate and magnesium carbonate. Such a mixture is sold commercially under the name of "Novadelox" or "Novadel." The dosage varies from 1 lb. per 25 bbl. to 1 lb. per 60 bbl. of flour. It is proportioned in dry feeders and, like the other bleaching agents, is thoroughly blended with the flour in special agitators. Benzoyl peroxide is relatively slow in its bleaching action. One or two days may be required for the reaction with the flour pigments to proceed to completion.²⁴

Agene and Novadelox are the bleaching agents which are commonly used for all hard wheat flours, while chlorine and Beta-Chlora are used for soft wheat flours, frequently with the addition of Novadelox.

3. Control of Amylase Activity and of Vitamin, Calcium, and Iron Contents

Frequently, the patent flours are low in amylase activity, a condition rectified by diastating, that is, by the addition of appropriate quantities of malted wheat flour or malted barley flour to bring the diastatic activity to about 300 units. Diastatic activity is expressed as the number of milligrams of maltose present in 10 g. of flour after autolysis for one hour under controlled conditions.²⁵

4. Other Milling Processes

(a) Soft Wheat Milling

Soft wheats are milled by the same general method of gradual reduction described for the hard or bread wheats. As the flours are used for a variety of purposes, each with special quality requirements, the soft wheat miller carefully selects his wheat and mills it in such a manner as to produce the type of flour desired for particular trades. Thus, patent flours containing about 9.5% protein milled from soft red winter wheat are especially suitable for baking chemically leavened biscuits and hot breads so largely consumed in the South. Special mixtures of soft wheats, including white wheats, are converted into well-known brands of cake flours for use in pastry and cake making. Such flours usually contain 8% or less of protein and are milled to very short patents (commonly about 30%), so that their ash content is also very low. Treatment with rather heavy dosages of chlorine to bring the *pH* to about 5.1 to 5.3 weakens the gluten and facilitates the production of "short" pastry. Cake flours are bolted through silk of finer mesh than biscuit or bread flours, the last mentioned having the coarsest granulation.

(b) Modified Processes

During the past 50 years, many mechanical improvements have been made in the gradual reduction process, and there has been an increasing measure of scientific control. Nevertheless, no appreciable changes have occurred in the general principles and methods employed. Recent nutritional trends have stimulated attempts to produce wheat flours of acceptable baking quality in which a larger proportion of the minerals and vitamins would be retained than in the conventional roller milling process. Two processes which have been promoted in the United States are outlined below.

Morris Process.—The so-called Morris milling process was patented in 1935. Essentially, it is a modification of the conventional roller milling procedure in which certain germ-rich mill stocks are finely ground, aerated, and incorporated in the flour.

Earle Process.—In 1941, commercial trials were initiated of a process for removing the outer bran of wheat before subjecting the grain to any grinding action. This "wheat peeling" process was invented by Theodore Earle, a mining engineer,

²⁵ *Cereal Laboratory Methods*. 4th ed., Am. Assoc. Cereal Chemists, Lincoln, Nebraska, 1941.

and employs the flotation principle used in concentrating ores.^{26, 27} The cleaned wheat is passed through a series of rubber-lined peeling units, or agitation cells, in which it is violently agitated under water by rubber-covered impellers to free the outer bran or beeswing. The last several cells in the series function as flotation units. A small quantity of pine oil is added as a flotation agent; and the outer bran which has been freed from the grain is carried to the surface by aeration and floated off on the froth. The wheat remains in the peeling and flotation units for about 9 min. The partially decorticated wheat is recovered by screening and centrifuging and is then dried at moderate temperatures to remove excess moisture. During drying, additional partially loosened bran is freed from the wheat and is removed by aspiration. The Earle process thus constitutes a new method of preparing wheat for grinding. The peeled wheat may be pulverized in a hammer mill type of mill, where a product similar to whole wheat flour is desired, or it may obviously be used in the gradual reduction roller milling process, and several grades of flour produced.

The beeswing removed by the peeling process averages 2% of the wheat and analyzes about 6.8% moisture, 3.1% protein, 1.3% ash, 0.4% fat, and 23.2% fiber. Analyses of the ground peeled wheat shows it to be somewhat higher in protein, lower in fiber, and similar to whole wheat flour in ash and thiamine.²⁶ The process is as yet only in the initial stages of commercial development.

(c) Durum Wheat Milling

In durum milling,²⁸ the object is the production of a maximum yield of highly purified middlings (semolina). Although the same sequence of operations (namely, cleaning, tempering, breaking, sizing, purification, and reduction) is involved in the production of semolina and flour, the milling systems differ materially in design. In milling flour, differences in the friability of the endosperm, bran, and germ on the smooth reduction rolls are an important aid in separating these products. In semolina manufacture, however, impurities and the mill offals must be removed by the cleaning and purifying systems. Durum wheat milling involves thorough cleaning and proper conditioning of the grain, light and careful grinding, and thorough purification. In order to accomplish the desired objectives the cleaning, breaking, sizing, and purifying systems must be much more elaborate and extensive than in mills designed for flour production; on the other hand, the reduction system is much shorter in durum mills because the primary product is removed and finished in the granular condition and the reduction rolls are only required for reduction of the tailings from the various parts of the middlings system.

In order to secure the maximum yield of large endosperm particles, break rolls with U-cut corrugations are employed. The break system is very extensive, to permit lighter and more gradual grinding than is employed in flour mills. The sizing system

²⁶ *Food Industries*, 13, No. 1, 70 (1941).

²⁷ G. C. Robinson, *American Miller*, 70 (1), 92 (1940).

²⁸ The outline of semolina milling is based on information obtained by Le Clerc (Ref. 29) from T. C. Roberts, General Mills, Inc., Minneapolis, Minnesota.

is also more elaborate than in flour milling, and is employed to resize middlings or partially refined semolina which contain too much bran to be considered finished products. Like the break rolls, the sizing rolls are corrugated, but the corrugations are finer and the rolls are not cut so deeply. After each breaking and sizing, the stocks are graded into several different sizes and the various middlings streams sent directly to the purifiers, upon the efficiency of which the ultimate degree of refinement depends.

Durum wheat of good milling quality normally yields about 62% semolina, 16% clear flour, and 22% feeds.²⁹

5. Yield of Mill Products in Flour Production

While the plump wheat grain consists of approximately 84% endosperm, 14% bran, and 2% germ, these three structures are by no means completely separated by the milling process. Normally, the yield of total flour varies from about 70 to 74% instead of the theoretical 84%; and the flour which is obtained contains some pulverized bran and germ. In ordinary milling processes only about 0.2% of germ is recovered as such.

The quantity of bran recovered in a relatively pure condition and sold as bran normally varies from about 12 to 16% of the wheat milled. The total remaining by-products are commonly approximately equal in quantity to the bran and, when bulked together (with at times the omission of a small percentage of feed flour), constitute gray shorts. The low-grade flour and feed middlings may be sold separately giving rise to a series of other feed by-products as defined on page 669, Volume I.

The more efficient the milling process, the greater is the yield of flour and other products for human consumption. As wheat is purchased in 60-lb. units (bushels) and flour has been sold until recently in 196-lb. units (barrels), it has been customary for the miller to express "yield" in terms of the number of bushels and pounds of *clean wheat* of natural moisture content (that is, before tempering) required to produce 1 bbl. or 196 lbs. of products for human consumption. For example, if flour is the only human food product produced, and the yield is 72% on the basis of the cleaned wheat before tempering, the miller expressed the yield as 4:32 (4 bu. and 32 lbs.). In the United States, a federal order effective June 1, 1943, required that the unit of flour, sales should be based on a sack of 100 lbs. rather than on a barrel of 196 lbs. Millers are therefore now expressing their yield figures as the number of bushels and pounds of wheat required to produce 100 lbs. of flour. The lower the millers' yield figure, the higher, of course, are the flour yield and the milling efficiency (assuming that the comparisons are made between wheats of equal moisture and endosperm content).

The lower the moisture content and the higher the test weight of the wheat, the greater, in general, is the potential flour yield. The relation between test weight and flour yield is not linear. Published reports indicate that each pound decrease in test weight results in decreases of about 0.6 to 0.8% in flour yield. Wheats of equal test

²⁹ J. A. Le Clerc, *Cereal Chem.*, 10, 383 (1933).

weights may, however, vary as much as 2% in flour yield, depending on the size and density of the kernel, as influenced by variety and environmental conditions.

6. Enrichment of Flours and Cereal Products

As the total quantity of the various required enriching ingredients amounts only to about 1 part per 20,000 parts of flour, it is necessary to add these in diluted form in order to secure accurate proportioning with a continuously moving flour stream. This is accomplished by means of a "master mix" or "premix." Some millers use premixes made by manufacturers; these are added to flour in amounts varying from $\frac{1}{4}$ to $\frac{1}{2}$ oz. per 100 lbs. Thiamine crystals have a tendency to acquire an electric charge and form "shot balls" in the flour so that special care must be taken to secure a uniform premix. Some mills prepare a seed batch by mixing the enriching ingredients with about 9 parts of monocalcium phosphate as filler in a ball mill; others use flour as a filler, and employ a combination of thorough sifting and mixing to break up any agglomerates. For this purpose, a relatively dry, short-extraction flour should be used. The seed batch is then converted into a bulkier mix which frequently contains about 5 lbs. of enriching ingredients per 1000 lbs.; this concentration requires a feeding rate of about one pound of the mixture per barrel of flour, and a malt feeder is satisfactory for proportioning such quantities.

In view of the catalytic effect of soluble iron salts in promoting the development of rancidity, insoluble forms of iron such as *ferrum reductum* and sodium iron pyrophosphate, are used as sources of iron in preparing enriched flour.

Because of the cost of the enriching ingredients, particularly riboflavin, every effort is made to see that they are applied in only the amounts necessary (plus a safety factor of approximately 10%), and that a sufficient length of conveyor, together with rebolting, is used to insure uniform distribution. In computing the dosage of enriching ingredients, allowances are made for their natural content in the flour. In the case of patent flours, the following average allowances may be made per pound of flour: thiamine, 0.30 mg.; riboflavin, 0.15 mg.; niacin, 3.5 mg.; and iron, 3.0 mg. These allowances are regarded as conservative for the majority of patent flours, although some soft wheat patents may average lower. In enriching straight or clear grades, it is important to remember that the increase in riboflavin with an increase in extraction is less than the increase in thiamine, niacin, or iron (see Table 138, Volume I). Many mills check the vitamin and iron levels in the unenriched flour, as well as in the enriched product, to insure maximum economy in the production of enriched flour, to meet the specifications given in Table 140, page 666, Volume I.

The addition of the optional enriching ingredients has not come into general use. With reference to wheat germ, not only would its presence increase the tendency of the flour to become rancid upon storage, but it has a marked deleterious effect upon baking properties.³⁰ Wheat germ of reduced moisture content which has been heat treated and/or mixed with certain oxidizing agents, such as potassium bromate, is offered to the bakery trade for incorporation with the flour at the time of mixing.

³⁰ D. E. Smith and W. F. Geddes, *Cereal Chem.*, **19**, 785 (1942).

The addition of vitamins and minerals to cereal products which are marketed in the form of large particles, such as corn grits or exploded wheat or rice, presents an entirely different problem from that involved in flour enrichment, since the agents cannot merely be mechanically mixed with the product in the dry state. For such products, the cereal may sometimes be moistened and then mixed with the vitamin carrier with or without the use of an adhesive binder such as sugar sirups, salt solution, dextrins, and oils or fats. Another method is to spray a suspension, paste, emulsion, or solution of the vitamin on the cereal.³¹ Patents have been granted (U. S. Patents No. 2,131,811, Oct. 4, 1938; and No. 2,259,543, Oct. 21, 1941) covering the mineral enrichment of cereal foods with calcium, iron, and phosphates, when the calcium and iron salts are coprecipitated with disodium phosphate to form a coarse agglomerate which remains dispersed in the cereal.

7. Wheat Flour Products

(a) Starch and Gluten

In the manufacture of wheat starch, the main problem is to separate the starch from the gluten in which it is embedded. In the early development of the wheat starch industry, the whole grain was used. The oldest method was the so-called Halle or fermentation process in which the grain, softened by steeping in water, was crushed and then made into a mash with water and allowed to undergo fermentation and putrefaction for several days. This treatment destroyed the bulk of the gluten and thereby facilitated the washing out of the starch. The gluten was considered an unavoidable evil and its recovery was a matter of minor importance because it was of little or no commercial value. This procedure was eventually displaced by the so-called Alsatian process, in which the grain was steeped and ground and the starch separated by washing without previous fermentation. In the last 50 to 100 years, wheat flour, rather than the grain, has been employed. The first successful method using wheat flour was described by Martin in 1837³² and most of the wheat starch now produced in the United States is being made by this method with certain technical improvements. The Martin process consists of mechanically washing the starch out of a dough.

In present-day American practice³³ wheat flour (usually clear grades) is made into a stiff dough with water and allowed to stand for about one hour to permit hydration of the endosperm proteins with the formation of gluten. The dough is then transferred to a gluten washing machine in which it is kneaded under a constant spray of water. The starch passes off with the water through sieves or perforations in the side of the washer, the wet gluten which remains behind being removed after each batch of dough has been washed. The starch suspension is passed over jig shakers

³¹ F. N. Peters, *Food Industries*, 13, 55 (1941).

³² L. Eynon and J. H. Lane., *Starch: Its Chemistry, Technology and Uses*. W. H. Heffer & Sons, Cambridge, 1928.

³³ The author is indebted to Mr. A. J. Patten, The Huron Milling Company, Inc., Harbor Beach, Michigan, for providing information used in preparing this section.

dressed with silk bolting cloth to remove any cellulose material, and is then conveyed to the starch tables or runs similar to those used in the preparation of cornstarch (see page 469). The tables consist of wooden troughs, 10 in. wide, 10 in. high, and about 80 ft. long, with a fall of about 2 in. from the head to the tail end. As the starch suspension flows slowly down the tables, the heavy or prime starch settles out while the smaller granule starch, known as No. 2 or "gluten starch," tails over and is conducted to large settling tanks.

After several inches of starch have been deposited on the runs, the surface is washed with water, and the starch flushed off the tables, dewatered and dried in a manner similar to that described for cornstarch (see page 470). For certain purposes, the starch may be purified by washing, sieving, and sedimenting before the final dewatering and drying. The tailings from the heavy starch are allowed to remain in the settling tanks until the gluten starch has settled; the clear supernatant liquid containing flour solubles is then drawn off, treated with lime, and pumped to filter beds. The wet gluten starch is dewatered and dried in the usual manner.

The wet crude gluten, as removed from the gluten washers, contains 65–70% of water. Where dried gluten is to be made in which the dough-forming characteristics are retained, the wet gluten must be dried at low temperatures. The wet gluten is cut into small pieces, placed on trays, and dried under vacuum in steam-heated driers. Normally, this operation is carried out under a vacuum of 28 in. of mercury and 30 lbs. steam pressure on the shelves. The gluten is generally dried to a moisture content of about 5%, after which it is ground and bolted. The product dried under such conditions is referred to as "gum gluten" and is suitable for fortifying low-protein flour for breadmaking or utilization in other food products. For certain food uses, stock feeds, and industrial purposes (such as the preparation of glutamic acid and monosodium glutamate), it is unnecessary to avoid higher temperatures in the drying process and the gluten may be dried on drum driers.

The Martin process provides ready recovery of wheat gluten and gives a good yield of starch but its application is limited to wheat flour having good doughing properties and it does not conveniently lend itself to large-scale operation. In a modification of this method, known as Fesca's process, the starch and gluten are separated by a centrifugal method but it is understood that a clear-cut separation of starch and protein is not obtained.³⁴

³⁴ Since this section was written the shortage of corn, coupled with the increased need for starch, has stimulated interest in the development of new methods for producing starch from wheat and other cereal grains. The Northern Regional Research Laboratory, U. S. Department of Agriculture, has developed three procedures for producing wheat starch: (1) the wet milling of wheat, described by R. L. Slotter and C. T. Langford, *Ind. Eng. Chem.*, **36**, 404 (1944); (2) an alkali process employing wheat flour in which the protein is dispersed in dilute alkali and the starch separated either by tabling or by centrifugation. From 50–80% of the flour protein having a purity of 60–90% is recovered by acidifying the starch-free alkaline protein solution and collecting the precipitated protein by centrifugation; and (3) a batter process employing wheat flour in which the flour is mixed with water to form a thin batter from which the starch can be washed out quickly. A general description of the alkali process and batter process has been published by G. E. Hilbert, R. J. Dimler, and C. E. Rist, *American Miller*, **72**, No. 4, 32 (1944).

The yields of starch and gluten vary somewhat depending upon the composition and grade of flour, but the following values are representative: prime starch, 50 to 55%; No. 2 or gluten starch, 10 to 20%; and gluten, 10 to 12%. A recovery of 75 to 80% of the total protein of the flour as gluten is considered good practice. The ratio of gluten to nongluten proteins in different flours varies rather widely, and some gluten is unavoidably lost during the washing process. Commercial gluten naturally varies in composition, but a typical analysis of a good grade is as follows: moisture, 5.1%; protein, 79.8%; total lipids, 7.8%; starch, 3.6%; ash, 1.5%; and undetermined, 2.2%. Gluten which is used for baking purposes must be prepared from flours of high gluten "quality," and care must be exercised to avoid heat denaturation during the drying process. This analysis conforms to the following definitions and standards for "ground gluten" promulgated in 1936 under the Food and Drugs Act:

Ground Gluten.—The product made from wheat flour by the almost complete removal of starch. It contains not more than 10% of moisture and, calculated on the water-free basis, not less than 14.2% of nitrogen, not more than 15% of nitrogen-free extract (using the protein factor 5.7), and not more than 5.5% of starch (as determined by the diastase method).

Gluten is used for the preparation of gluten flours and in the manufacture of monosodium glutamate. The patent literature discloses that gluten has been included, among other cereal proteins, as a protein for making plastics. No successful commercial development of plastics from wheat proteins has yet been made because of the high cost of the material and the fact that the plastics which have so far been prepared are too hygroscopic to make them generally useful.

Wheat starch is employed chiefly in the laundry and textile industries, but some is used in making adhesives.

(b) *Gluten Flour*

Gluten flour³³ is prepared by blending ground gluten with a good grade of patent flour to conform with the following definition and standards promulgated in 1936 under the Food and Drugs Act:

Gluten Flour.—The product made from wheat flour by the removal of a large part of the starch. It contains not more than 10% of moisture and, calculated on the water-free basis, not less than 7.1% of nitrogen, not more than 56% of nitrogen-free extract (using the protein factor 5.7), and not more than 44% of starch (as determined by the diastase method).

Gluten flour is used in making bread and other low carbohydrate foods for diabetics.

(c) *Monosodium Glutamate*

The gluten proteins are unique in that they contain a very high percentage of *d*-glutamic acid. See Table 120, p. 618, Vol. I. The monosodium salt of *d*-glutamic acid has a strong, meatlike taste. Wheat gluten has been extensively employed for many years in China and Japan for the manufacture of glutamic acid and monosodium

glutamate (known as "ajinomoto") for use as a food condiment; limited quantities of such preparations were imported to this country, but until very recently found a very limited sale. Today, however, considerable quantities of monosodium glutamate, and other flavoring materials having the same taste characteristics, are being manufactured in America for use by the food canning and dehydration industries. Monosodium glutamate is now made both from wheat gluten and Steffen's waste water, a by-product of the sugar beet industry. The main chemical steps involved in its preparation from wheat gluten are: preparation of glutamic acid hydrochloride; preparation of glutamic acid; and preparation of monosodium glutamate.³⁵

Wet wheat gluten (or steamed dry gluten) is hydrolyzed by heating with concentrated hydrochloric acid in a closed, steam-jacketed kettle. The insoluble humin which forms is removed by filtration. On cooling the hydrolyzate, crude glutamic acid hydrochloride crystallizes out and is filtered off. The crude hydrochloride is then dissolved in water and converted to the free acid by adjusting the pH to 3.2 (± 0.2), the isoelectric point of glutamic acid. The glutamic acid slowly crystallizes out over a period of several days and, after filtering, is dissolved in water and converted to monosodium glutamate by neutralization with sodium hydroxide or sodium carbonate. Decolorizing agents are then added, and the solution filtered and concentrated. The monosodium glutamate is allowed to crystallize from the concentrated solution and is recovered by filtration. The yield is about 25% of the weight of the gluten. Modifications of the above process are practiced; and several patents have been issued covering methods for improving the yields. One of the most recent (U. S. Patent No. 2,306,646) involves the addition of ethanol to the mother liquor during crystallization in order to provide a medium in which the salt is less soluble.

8. Macaroni Manufacture

(a) Long-Goods

The steps in macaroni manufacture are mixing, kneading, pressing, and curing or drying. Throughout the process of manufacture, every effort is made to develop and retain the maximum intensity of yellow pigmentation. The methods employed have been well covered by Le Clerc.²⁹

Mixing.—When making "long-goods," the farinaceous material, water, sometimes salt and other optional substances (together with such additional ingredients as egg, milk, soy, and vegetable products when special kinds of macaroni are made; see page 676, Volume I) are mixed in large, slow-speed mixers until the granular appearance of the mix is about to disappear. The absorption (lbs. water per 100 lbs. farinaceous material) varies from 25–30%, but is usually about 26% or somewhat less than one-half that normally employed in making bread doughs. A low absorption is favored because all water added must be later removed in the drying process;

³⁵ The author is indebted to Dr. C. G. Ferrari, Research Department, General Mills, Inc., Minneapolis, Minnesota, for providing the information used in preparing this section.

the coarser the granulation, the higher the room temperature, and the higher the relative humidity of the mixing room, the smaller is the amount of water added. Less water is required when semolina is used as the raw material. Doughs of lower mobility are made for vermicelli rather than for macaroni manufacture. Within limits, however, an increase in absorption results in a better color in the finished product. The mixing is conducted in such a manner as to secure minimum development of the gluten and with a minimum heat of friction which would reduce color. The temperature of the water varies from 70-140° F., and the dough, after mixing for 10-20 min., is usually brought out at a temperature between 80-100° F.

Kneading.—After mixing, the dough is transferred to the kneading machine or gramola (Fig. 92), consisting of a flat-bottomed, revolving steel pan about 8 ft. in

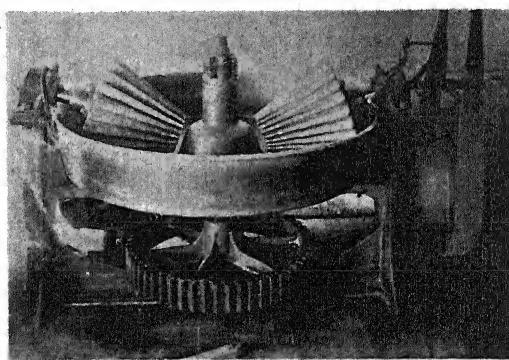


Fig. 92.—Macaroni kneader or gramola. (Figs. 92-94 courtesy National Macaroni Manufacturer's Association, Braidwood, Ill.)

diameter. Two conical, corrugated, cast-iron rolls resembling bevel gears, one at each side of the pan, knead the dough as the rotation of the pan passes it under them. The clearance of the rolls, and hence the vigor of the kneading, is adjusted by a hand wheel; a small adjustable plow turns the dough back into the path of the rolls. During kneading, the grainy or granular structure of the mixture disappears and it is transformed into a very stiff, plastic mass which is creamy yellow in color and translucent in thin layers. The kneading operation is carefully watched, and is continued only until the desired degree of homogeneity is obtained, as mixing beyond this point reduces color. Kneading usually requires from 10 to 20 min.

Pressing.—The dough from the kneader, after resting for a few minutes, is transferred to a large vertical hydraulic press (Fig. 93) in the bottom of which the appropriate die or perforated plate, called a trafile, is located. In the instance of a macaroni die, each hole has a centrally located steel pin which forms the hole in the macaroni. By means of a descending piston, the dough is forced through the die at a pressure of from 2500 to 5000 lbs. per sq. in. The walls of the press are jacketed, through which

water at from 110–130° F. is circulated, in order to keep the die plate warm and the dough mass plastic. Maintenance of a uniform temperature is essential in order that the macaroni will extrude from the inner and outer holes of the die at the same rate. Too high a temperature during pressing results in a loss of color also, improper conditions at this stage may yield a product having an undesirable rough surface. When

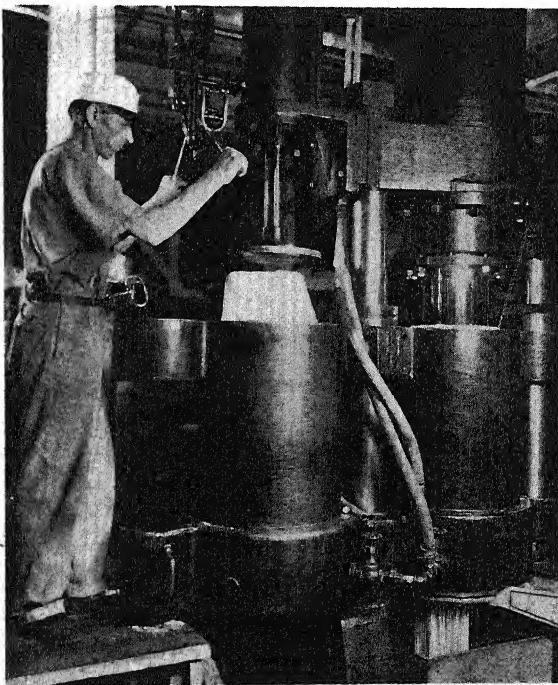


Fig. 93.—Vertical macaroni press used in the manufacture of long-goods. At left, hard dough is being packed in cylinder of press; at right, macaroni is extruding from bottom of cylinder through shaping die.

the extruded strands or rods, which are caught in a wooden trough placed under the press, are the desired length (30–50 in.), they are cut off by means of a knife and bent over wooden rods which are suspended in a special framework mounted on wheel trucks for transportation to the preliminary fanning or drying room.

The above outline of mixing, kneading, and pressing describes the conventional methods by which these operations have been carried on for many years. In line with the modern trend of replacing batch operations with continuous processes, machines have recently been placed on the market which proportion the ingredients, mix, knead, and press the dough into the desired shapes in an automatic continuous working process. For the production of long-goods, accessory devices known as mechanical spreaders are available, machines which uniformly distribute the extruded long-goods

over the sticks, and automatically trim the macaroni to the desired length. The suspension and spreading device is equipped with two distributor heads, each containing a number of small die holders, each of which carries a small die. The holes in each die are arranged so that the extruded strands are guided to the sticks in close formation without crossing each other. These extruded goods are predried by means of a blower and automatically pass on to the sticks which are carried on an endless chain. As soon as the goods have reached the proper length, which can be regulated as desired, they are cut automatically. In order to avoid small irregularities in the length of goods, the sticks carrying the suspended goods pass over a second cutter, which clips off any small protruding ends. These trimmings drop onto a conveyor belt from which they can be returned into the mixer of the continuous machine by a small conveyor. A motor drive with variable speed regulator, which controls the operating speed of the suspension device, is built into the machine. The empty sticks are placed into a magazine and by means of scoopers are fed to a moving chain which guides them to the suspension device. The sticks loaded with goods cut to the proper length are accumulated for removal to the drier.

Drying or Curing.—The preliminary drying of macaroni is carried out with a heavy current of dry air (40–50% relative humidity) for about 20 min. or until the macaroni firms up and the strands show a tendency to curl. This treatment is necessary in order to prevent souring and in order to "caseharden" the macaroni, thereby eliminating excessive stretching. From the fanning room, the casehardened material is transferred to the drying chamber proper where it is allowed to "rest" or "sweat" for 1–2 hrs. or longer to permit attainment of equilibrium in moisture distribution.

Drying, or curing, is the most critical stage of the entire manufacturing process. If the operation is unduly rapid, surface drying occurs, and if too slow, there is a danger of biochemical changes like souring or molding taking place. Macaroni contracts as it dries. If the rate of drying is so rapid that the outside becomes hard and dry before the interior is brought to the same state of dryness, the plastic interior is somewhat compressed by the contracting outer layers. Then, when the interior becomes dry, it contracts and causes the outside nonresilient structure to crack, check, or split. The critical factor in the drying operation appears to be the rate of diffusion from the center to the outside of the material; and the ideal drying condition is one that will remove the surface moisture at a rate which parallels this diffusion.

Under the conditions of open-air drying, such as are found in some parts of Italy, the moisture-laden sea breezes have approximately the correct humidity to extract the moisture from macaroni without causing cracking. The manufacturers became proficient in sensing the proper rate of drying by "feeling" the macaroni: if it was proceeding too rapidly, the product would be removed to a closed room and allowed to "sweat" until the moisture became uniformly distributed. By a repetition of this drying and sweating process the macaroni was cured in from 10–14 days.

In modern commercial practice, this empirical, slow, and unhygienic method is replaced by cabinet drying, in which the relative humidities and temperatures of the circulating air are regulated in such a way as to effect a rate of moisture interchange

which will result in uniform drying. Initially, air at about 93% relative humidity is circulated, and the humidity is gradually lowered to approximately 60%. The drying is complete in from 36–90 hrs., depending upon the efficiency of the process and the nature of the product. In some plants, drying cabinets equipped with automatic temperature and humidity control are employed. In others, the humidity gradient is provided by:

1. Progressively raising the temperature of the drying air from about 70 to 140° F.
2. Allowing an increasing proportion of the moisture-laden air to vent to the atmosphere and replacing it by air at atmospheric humidity.
3. Or combining (1) and (2).

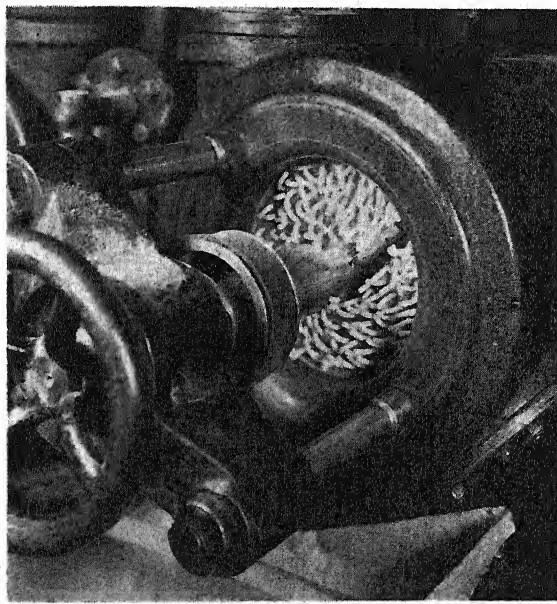


Fig. 94.—Horizontal macaroni press for short-goods, showing revolving knife cutting elbow macaroni.

In plants without automatic control, alternate "drying" and "rest" periods are frequently employed. When properly cured, the product contains from 10–11% moisture. Hoskins³⁶ has presented a detailed drying schedule for commercial practice. Binnington and Geddes³⁷ have devised an experimental drying cabinet and have determined the moisture content of macaroni in equilibrium with air at various relative humidities.

When thoroughly dry, the macaroni is trimmed to uniform length, or the "elbows"

³⁶ G. G. Hoskins, *Food Industries*, 4, 48 (1932).

³⁷ D. S. Binnington and W. F. Geddes, *Can. J. Research*, 10, 221 (1934).

may be sawed off and the resulting straight pieces sawed into various lengths for the package trade.

In general, 100 lbs. of farinaceous material will yield 94 lbs. of marketable macaroni products. About 4% of the apparent loss is due to the difference between the moisture content of the macaroni and the raw material. The average proximate composition of macaroni is given in Table 126, page 629, Volume I.

(b) *Short-Goods*

For short-goods, the farinaceous ingredient usually consists of hard wheat flour. In the manufacture of elbows, horizontal presses (see Fig. 94) are employed. A revolving knife cuts the macaroni at the outer face of the die. The speed of the knife determines the length of the product. In the instance of such shapes as animals, alphabets, stars, etc., the dough is rolled into a thin sheet and the figures stamped out. The formed pieces of short-goods are spread evenly on screen trays and dried in cabinets through which hot air is circulated. The drying conditions for short-goods are not so critical as for long-goods.

(c) *Noodles*

Noodles, which are ribbon-shaped, differ from other macaroni products in that they must contain at least 5.5% of the solids of egg or egg yolk calculated on the moisture-free basis. Certain optional flavoring ingredients may be added. In addition to plain noodles, the proposed federal definitions and standards provide for the manufacture of wheat and soy noodle products and vegetable noodle products. See page 676, Volume I.

In noodle production, the farinaceous ingredient is usually hard wheat flour. The various ingredients are mixed and kneaded into a stiff dough as in the manufacture of macaroni. The resulting dough is passed through a series of sheeting rolls to form sheets $\frac{1}{8}$ in. thick or less, after which it is cut into thin strips by means of a shredding machine. The strips are folded, placed in drying trays, and dried for from 24 to 48 hrs. The average proximate composition of egg noodles is given in Table 126, page 629, Volume I.

VIII. READY-TO-SERVE CEREAL BREAKFAST FOODS

Ready-to-serve cereal breakfast foods³³ may be conveniently classified into two general types: those made from entire grains or their mill products; and those made from fabricated cereal products. Both these types are found on the consumer market in the form of flaked, shredded, puffed, and toasted breakfast foods; considerable variations exist within each type in regard to the cereals employed, the amount and

³³ The author is indebted to C. G. Ferrari, General Mills Inc., Minneapolis, Minn.; S. N. Holiday, National Biscuit Co., New York; A. G. Olsen, General Foods Corp., Hoboken, N. J.; and M. R. Warren, The Quaker Oats Co., Cedar Rapids, Ia., for their courtesy in supplying material for this section.

kind of cooking, and the flavoring used. Some of the preparations have no product patent protection; others are made using equipment that is covered by patents; and still others have one or more steps in the process, for example, the method of vitamin or mineral fortification, protected.

1. Flaked Breakfast Cereals

The first ready-to-serve breakfast cereals to be placed on the market in flake form were made from corn, rice, and wheat or their mill products, but today several fabricated cereal products are merchandized in this form.^{38a} In the former case, the grain product is usually tempered, or cooked and tempered, flavored, flaked, dried, and toasted; variations exist in the order of these steps and some may be omitted. An outline (see Fig. 95) of the manufacture of corn flakes will serve to illustrate the processes involved.

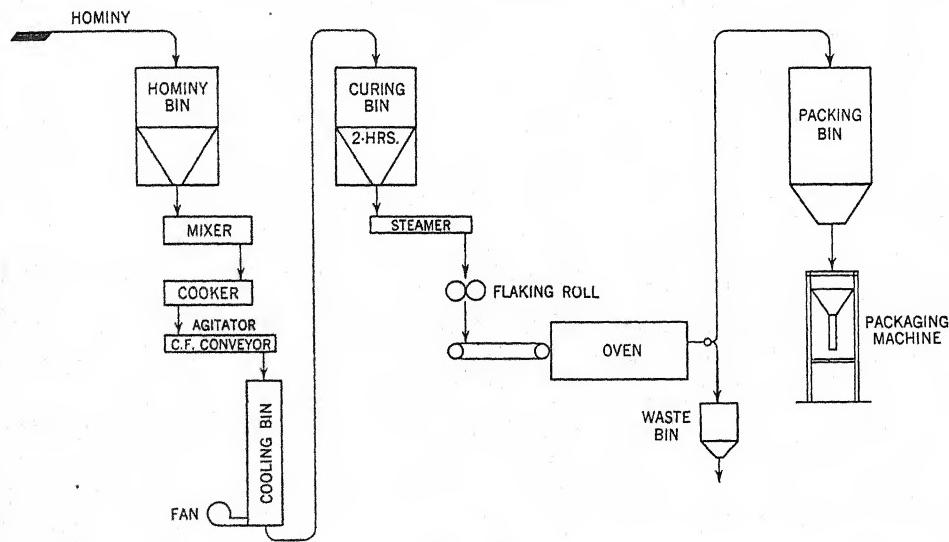


Fig. 95.—Flowsheet illustrating the steps involved in the manufacture of corn flakes.
(Courtesy General Mill Equipment Co., Kansas City, Mo.)

(a) Corn Flake Manufacture

The corn grits, or hominy, employed for flaking purposes are produced from white corn on a corn mill using the degerminating process, as outlined on page 461. Only the larger sizes of hominy which have been thoroughly polished to remove all bran are suitable for flaking. In general, the flaking hominy is of such a size that it will pass

^{38a} Illustrations of flaked product patents are: U. S. 1,483,515, Feb. 12, 1924; U. S. 2,093,260, Sept. 14, 1937; U. S. 2,093,285, Sept. 14, 1937; U. S. 2,131,450, Sept. 27, 1938; and U. S. 2,174,982, Oct. 3, 1939.

through a No. 4 wire mesh screen but will be retained on a No. 6 mesh screen. The larger producers make their own grits, and store them in concrete storage bins of the type used in grain storage.

The various steps in the actual manufacture of corn flakes are schematically outlined in Fig. 95. The hominy is first cooked in rotary steam cookers (Fig. 96) capable of handling a batch of from 1200-1800 lbs. at one time. The hominy is weighed into the cookers where it is cooked with live steam for 2 to $2\frac{1}{2}$ hrs. and mixed with flavoring materials. The flavoring syrup may be made only from sucrose, salt, and water, or may contain such added ingredients as malt syrup, maple syrup, honey, and the like.

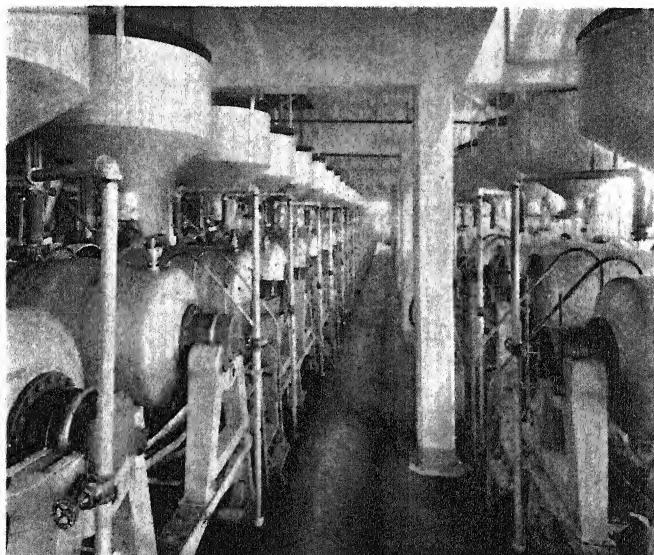


Fig. 96.—Corn flake manufacture. Rotary steam cookers in which flaking hominy is cooked. The hominy is fed into cookers by gravity and the cooked product is conveyed by belt conveyors. (Figs. 96 and 97 courtesy General Foods Corporation, Battle Creek, Mich.)

The cooked grits are carried to an agitator, or lump breaker, and then are discharged onto a pan cooler (see Fig. 97) consisting of an open pan from 4-8 ft. in diameter equipped with mechanically driven stirrers or agitators. The product is next passed to gravity-type driers through which preheated air is blown to reduce the moisture content to the desired degree (approximately 15%). The dried material is held in tempering tanks for several hours in order to permit the residual moisture to become equally distributed; this is essential in order to obtain the uniform toughness necessary for flaking. The tempering period varies, but is generally about 24 hrs. for corn. The moisture content of the cooked hominy going to the rolls must be carefully controlled. If it is too high, the flakes are extremely thin; if it is too low, the flakes are too thick and there is undue loss from pulverization. The tempered material is

next passed through a heavy-duty flaking machine having a pair of water-cooled rolls 20 in. in diameter and 24 in. long, operating at a pressure of 75 tons; each flaking machine requires 30 horsepower for operation. The flakes are spouted as directly as possible to rotary ovens for toasting. The ovens are usually gas-fired and consist of a slightly conical, cylindrical, rotating, finely perforated metal screen about 4 ft. in diameter and 20 ft. long enclosed in a well-insulated outer jacket or housing which is exhausted to the atmosphere for the removal of moisture and fumes. In rotating, the flakes are continuously carried forward until they drop onto a conveyor at the time the proper degree of toasting has been accomplished. By close control of the

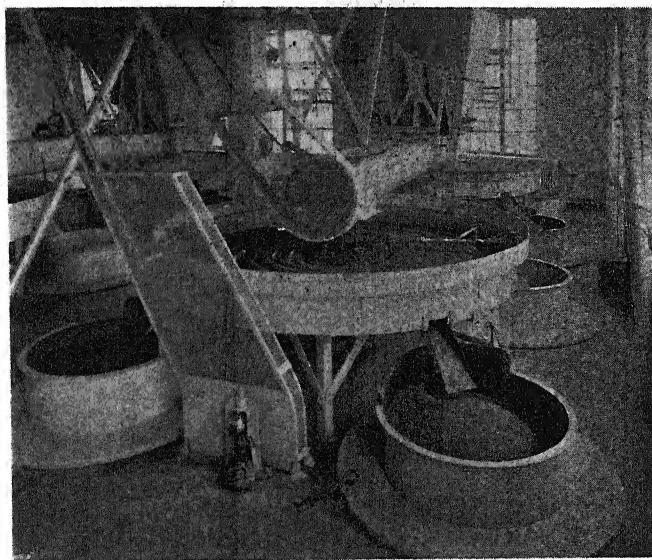


Fig. 97.—Corn flake manufacture. Pan coolers used in cooling the cooked corn preparatory to drying, flaking, and toasting.

toasting temperature and moisture conditions, a bubbly appearance can be produced in the finished flakes. The toasted flakes are inspected on the conveyor belt; sub-standard flakes being diverted to a conveyor leading to the feed room. The properly toasted flakes are carried to a screening and cooling device for the removal of broken flakes and cooling of the product, and thence to the packing bins. Much inventive genius has been utilized in the perfection of the automatic packaging of corn flakes and other cereal preparations.³⁹ In packaging, the flakes are weighed, placed in cartons, and sealed mechanically (Fig. 98). Photographs of white dent corn, flaking hominy, cooked and dried hominy, and finished flakes are reproduced in Fig. 99.

The entire process from the corn mill to the finished product is practically auto-

³⁹ P. P. Pratt, *Trans. Am. Soc. Mech. Eng.*, 53, No. 4, 49 (1931).



Fig. 98.—Corn flake manufacture showing an 18-oz. corn flake packing line in foreground and a second 18-oz. line in background parallel with it. Compression drier belt, carton sealer, Hooper rotary filler, and Johnson carton maker and liner at the extreme upper right-hand corner. Production rate, 62 cartons per minute of 18-oz. each packed as T24-18. (Courtesy General Foods Corp., Post Products Division, Battle Creek, Mich.)

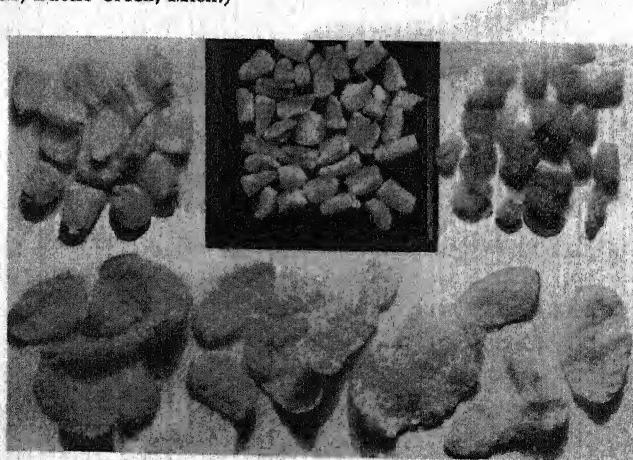


Fig. 99.—Corn flake manufacture. Top row: left, white dent corn; center, flaking hominy; right, cooked and dried hominy ready for flaking. Bottom row: finished corn flakes. (Courtesy General Foods Corp., Battle Creek, Mich.)

matic, with only a sufficient amount of expert human supervision to assure the proper functioning of the processing equipment, conveyors, and packing machinery.

(b) *Bran Flakes, Rice Flakes, Wheat Flakes*

The manufacture of bran flakes, rice flakes, and whole wheat flakes (such as "Wheaties") is carried out by the same methods as described for corn flakes. The cooking temperatures, time allowed for tempering, and the moisture content of the material going to the rolls differ for each cereal. Thus, the tempering period is commonly about 8 hrs. for wheat, and 72 hrs. for rice, as compared with 24 hrs. for corn.

2. Puffed Breakfast Cereals

Manufacturers of cereal products have made rather general use of the puffing or explosive process first developed by Anderson in 1904 for use with wheat and rice.⁴⁰ Initially, only these two grains were employed, but later the process was expanded to include barley, buckwheat, corn, millet, navy beans, peas, rye, and soybeans.⁴¹ In addition, puffed breakfast foods are now also prepared from cooked doughs.⁴²

In principle, the puffing procedure is rather simple. The grains or doughs to be puffed are enclosed in a pressure chamber, or puffing gun, and heated, whereby the aqueous vapor pressure is gradually increased; upon suddenly releasing the pressure by opening the gun, the expansion of the water vapor and other gases results in the explosion or enlargement of the products to several times their original volumes.

The design of puffing guns used in the preparation of cereals has been the subject of numerous patents.⁴³ Puffing equipment of various capacities is made in both stationary and revolving types. In order to secure a uniformly enlarged product, it is necessary that the pressure be reduced almost instantaneously. The guns must therefore have a large, quick-opening head or valve. As a general rule, steam developed either from the moisture in the material or introduced into the gun from an outside source is the "explosion intermediate." The gun must be constructed of noncorrosive material of sufficient strength to withstand the pressures developed; steel or bronze guns are generally employed. Since heat plays a very important part in the cooking or conditioning of the material preparatory to explosion, it is convenient to enclose the gun in an oven or chamber where outside heat is applied. However, some prod-

⁴⁰ Alexander Pierce Anderson, U. S. 766,212, Aug. 2, 1904.

⁴¹ Illustrations of patents upon the "whole-grain" types of puffed cereals are: U. S. 990,093, April 18, 1911; U. S. 1,321,754, Nov. 11, 1919; U. S. 1,395,015, Oct. 25, 1921; U. S. 1,832,813, Nov. 17, 1931; U. S. 1,925,267, Sept. 5, 1933; U. S. 2,124,746, July 26, 1938; U. S. 2,156,022, April 25, 1939; U. S. 2,181,372, Nov. 28, 1939; U. S. 2,185,054, Dec. 26, 1939; U. S. 2,190,949, Feb. 20, 1940; U. S. 2,269,536, Jan. 18, 1942; U. S. 2,292,274, Aug. 4, 1942; U. S. 2,264,574, Dec. 2, 1941; U. S. 2,295,116, Sept. 8, 1942.

⁴² Illustrations of patents covering the preparation of puffed breakfast cereals from doughs are: U. S. 1,725,171, Aug. 20, 1929; U. S. 2,162,376, June 13, 1939.

⁴³ Illustrations of patents covering the design of puffing guns are: U. S. 1,878,782, Sept. 20, 1932; U. S. 1,924,826, Aug. 29, 1933; U. S. 1,924,827, Aug. 29, 1933; U. S. 2,026,734, Jan. 7, 1936; U. S. 2,149,156, Feb. 28, 1939; U. S. 2,263,301, Nov. 18, 1941; U. S. 2,279,868, April 14, 1942.

ucts do not require the use of outside heat, the necessary temperatures being attained by superheating the steam or gas used for exploding before its introduction into the gun. In the cereal field, a rotary gun placed in an oven and provided with a quick-opening head at one end and a steam inlet at the other, is the type of equipment most generally employed. The moisture content of the material and the pressure, temperature, and time of cooking are varied to suit the product, and must be carefully controlled in order to secure optimum results. In the patent literature, temperatures of 125–300° C. are mentioned. Much lower pressures are required in puffing doughs than are necessary to secure satisfactory results with grains.

The increase in volume which results from the puffing operation varies with the cereal. Thus, with wheat and rice a tenfold increase in volume may be obtained, whereas with peas, peanuts, and soybeans, the maximum increase is only about twice that of the unpuffed product.

(a) Puffed Wheat Manufacture

The steps involved in the manufacture of puffed wheat are outlined in Fig. 100. Amber durum wheat is usually employed. The grain is thoroughly cleaned, dried to the proper moisture content for explosion, pearled to remove the bran, cooked in

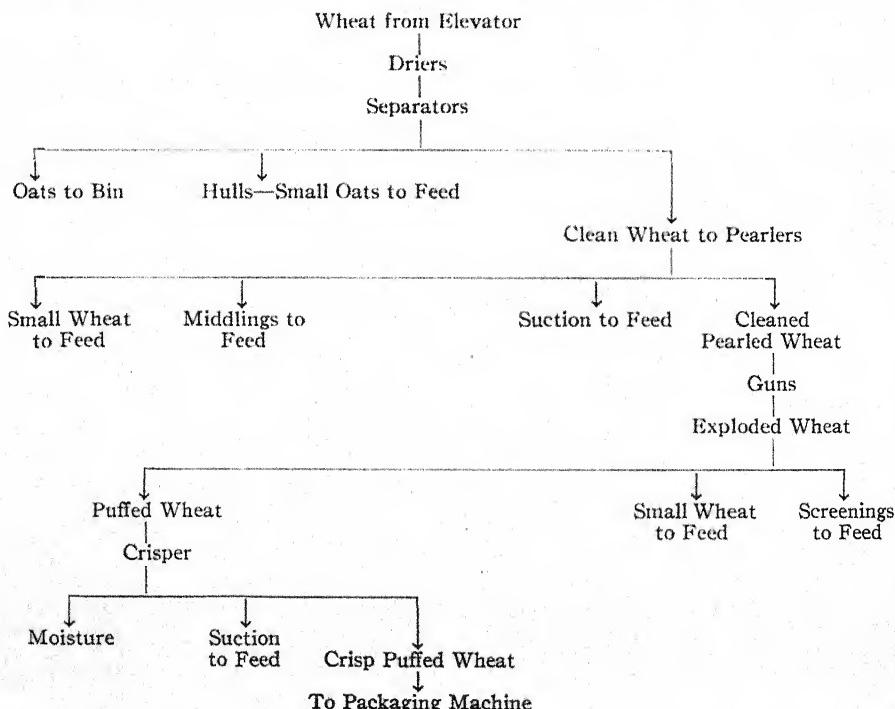


Fig. 100.—Flowsheet for the manufacture of puffed wheat. (Courtesy M. R. Warren, The Quaker Oats Co., Cedar Rapids, Iowa.)

puffing guns, and exploded. Since the wheat is released from a steam-filled atmosphere, its moisture content must be reduced to obtain a crisp product. This is accomplished just prior to packaging by means of either a rotary- or shaker-type of toaster. In order that this and other toasted cereals may reach the consumer in a crisp condition, it is necessary to use a well-sealed moistureproof package.

(b) *Puffed Cereal Breakfast Foods Fabricated from Doughs*

"Kix" and "Cheerioats" are examples of puffed cereal products made from doughs. In the case of Kix, the farinaceous ingredient consists of corn cones (corn meal). In Cheerioats, a mixture of ground oatmeal (75%) and corn and rye flours (20%) is used. The farinaceous materials, together with sugar, vegetable oil, vitamins, salt, and other mineral ingredients, are mixed into a stiff dough which is cooked and forced through an extruding die. As the formed pieces of dough emerge from the die, a revolving knife cuts them into pellets of the desired size. The pellets are then slowly dried to the moisture content required for puffing. After tempering, the dried pellets are placed in a puffing gun which is slowly heated until the appropriate pressure develops for puffing. The product is then puffed by releasing the pressure.

By employing doughs, it is possible to prepare cereal breakfast foods of widely varying chemical composition.

3. Shredded Breakfast Cereals

Whole wheat is used in the preparation of shredded breakfast cereals which are commonly formed into a "biscuit." In manufacture, the thoroughly cleaned wheat is weighed into pressure cookers, an equal weight of water added, and steam automatically injected into the cooker until the pressure, and therefore the temperature, have reached the desired point. A common type of cooker consists of a cast-iron shell with an inner cylinder of perforated metal which contains the wheat. During the cooking process, the wheat is carefully stirred by a series of paddles. The temperature and time of cooking vary with different wheat blends and are regulated so as completely to gelatinize the starch without disintegration of the kernels. When the cooking is completed, the excess water is drained off and the wheat, which contains about 50% moisture and has swollen to about twice its natural size, is discharged in a thin layer into a cooling tower, from which it passes into storage tanks for curing or conditioning. From the curing tanks, the wheat is conveyed to a shredding machine which has a series of shredding heads, each consisting of a pair of rolls. One roll is smooth, while the other has about 20 circular grooves per linear inch cut in its surface. As the rolls revolve toward each other, the wheat is forced into the grooves under about 1700 lbs. pressure and drops in a continuous flow of slender strands onto a moving bucket chain below. Layer on layer, the shreds fall from each pair of rolls until, at the end of the long machine, the desired thickness has been obtained. The thickness may be readily regulated by varying the number of shredding heads in operation. As the bucket chain full of shreds approaches the end of the shredder,

flat-edged knives operating from both above and below the shreds cut them into proper biscuit lengths. Flat-edged rather than sharp knives are employed in order to secure a selvedge edge which will seal the shreds and form the sides of the biscuit. The biscuits are automatically transferred to baking pans by an ingenious vacuum process and baked in reel-type ovens at 500° F. for about 20 min. Upon removal from the oven, the pans of biscuits are placed in racks and conveyed through a long drying tunnel in order to obtain a crisp dry product. The biscuits are then allowed to cool before packaging.

"Krumbles" is a shredded cereal product prepared by cooking wheat with malt extract and other flavoring materials, partially drying the cooked material, shredding, drying, cooling, and packing.

4. Granular Ready-Prepared Breakfast Cereals

The granular type of prepared breakfast food is represented by "Grape Nuts" which C. W. Post began to manufacture in 1898. Grape Nuts is a combination of

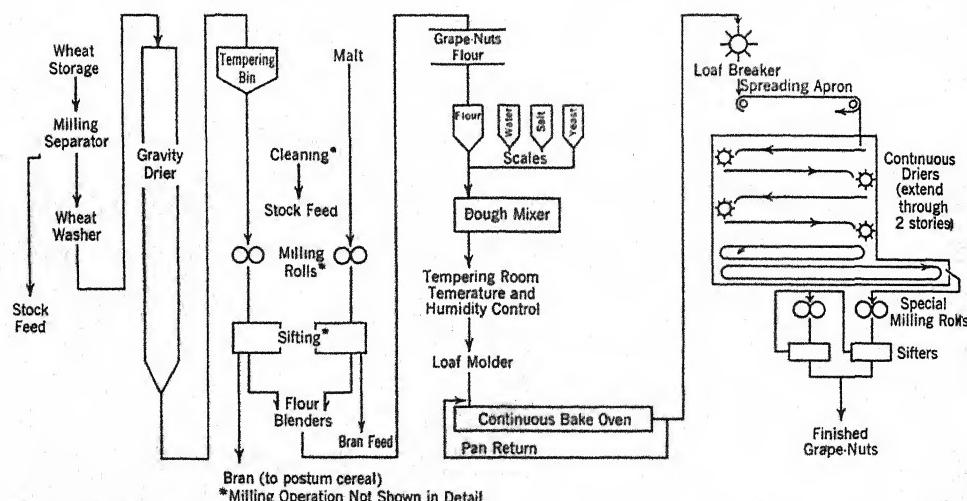


Fig. 101.—Flowsheet for the Grape-Nuts Process. (Courtesy Dr. A. G. Olsen, General Foods Corp., Battle Creek, Mich.)

wheat flour and malted barley flour which is mixed with yeast, salt, and water and allowed to rise for a time. The dough is then moulded into loaves, baked, and then crumbled and rebaked for several hours, after which it is ground between special rolls to give the well-known granular product.³⁹

A flowsheet of the Grape Nuts process is given in Fig. 101. Soft red winter and soft white winter wheats are cleaned, tempered, and milled. Only the coarse bran coating is removed in the milling operation and about 85% of the kernel, including the fine

bran and germ, goes into the Grape Nuts flour. This flour also contains sufficient malted barley flour to produce the desired conversion of starch during fermentation and baking. A straight dough is prepared from Grape Nuts flour with water, salt, and yeast. Much less yeast is used than in normal bread production since a rather dense, close-grained crumb is required to produce the desired granular product. The doughs are fermented for $4\frac{1}{2}$ to 5 hrs. at 80° F., during which considerable starch liquefaction occurs. The fermented dough is divided, moulded, automatically dropped into baking pans, and baked in traveling ovens for a much longer time than is employed in normal bread production. Each loaf weighs approximately 10 lbs. The loaves are then passed through a breaking device and the crumbled product is rebaked or dried, in continuous driers, for several hours. The material passes over 8 conveyor flights designed to handle relatively soft moist particles within the first half and smaller dry particles within the other half. The dried material is then crushed between coarsely corrugated special mill rolls, graded to secure the desired proportions of coarse and fine granules, and packed. Grape Nuts are also merchandised in flake form.

The density, sweetness, solubility and characteristic flavor of Grape Nuts is in large measure the result of the proper control of amylase activity; while considerable starch conversion occurs during the fermentation of the dough, the action of the amylases is greatly accelerated during the initial stages of the baking process. About 45% of the total solids of Grape Nuts is soluble in hot water; of this 15-17% consists of maltose, so that a considerable percentage of dextrin is indicated. The hydrogen-ion concentration of the finished product is equivalent to about pH 5.3.

The patent literature contains references to several types of special cereals; but in general they are modifications of the processes already described.⁴⁴

5. Mineral and Vitamin Additions

In addition to the processing of the cereal grains to produce ready-to-serve breakfast foods, minerals and vitamins are frequently added. The product may be either "restored" or "fortified," depending upon the nature and amount of the materials used. For example, minerals are added in the manufacture of restored cereals to compensate for losses in preparation as a result of the dilution of the basic raw materials in formula preparation, or, in the case of fortified amounts, are added in excess of those ordinarily present in the whole grain from which the product was made. An example of mineral restoration is provided by the General Mills product, Cheerioats, to which minerals supplying calcium, phosphorus, and iron are added in sufficient amounts to compensate for the use of noncereal ingredients in the formula and thereby meet the claim of whole-grain (oatmeal) levels. Kix, on the other hand, has an artificial relationship between calcium and phosphorus, as compared with corn. It will be recalled that cereals have an undesirably low calcium:phosphorus ratio; and in Kix

⁴⁴ Illustrations of patents covering the preparation of special breakfast foods are: U. S. 2,026,034, Dec. 31, 1935; U. S. 2,116,634, May 10, 1938; U. S. 2,182,175, Dec. 5, 1939.

manufacture the product is fortified with calcium in order to obtain a nutritional balance in regard to the relative quantities of calcium and phosphorus.⁴⁵

In the processing of cereal breakfast foods from whole grains where high temperatures or long cooking operations are employed, the thiamine is partially destroyed. It is, accordingly, necessary to restore this vitamin if claims of whole-grain or natural levels are made. As in the instance of the minerals, the refinement of the cereals and the dilution of the basic raw materials in formula preparation necessitate the restoration of thiamine, riboflavin, and niacin in certain ready-prepared breakfast foods if claims are made that natural or whole-grain levels are present in the finished product. Other vitamins, such as vitamin D, which are not normally present in cereals, may be added to produce a fortified product.⁴⁶ The methods employed in incorporating vitamins and minerals have been outlined on page 494. It should be re-emphasized that thiamine is partially destroyed at high temperatures. Accordingly, in the preparation of ready-to-serve cereal breakfast foods, this vitamin is added after the product has been processed.

IX. CEREAL COFFEE SUBSTITUTES

Roasted cereals have long been used as substitutes for coffee. At one time there were a number of such preparations enjoying a large sale in the United States. "Postum Cereal," developed by C. W. Post in the late nineties, is a representative product of this type. A soluble, vacuum-dried extract of Postum Cereal, known as "Instant Postum," was placed on the market in 1912. See also page 856, Volume I.

The major operations involved in the manufacture of these products have been described by Pratt.⁴⁷ In the preparation of Postum Cereal, whole wheat is carefully roasted in gas-heated rotary roasters, granulated, and blended in specific proportions with a similarly roasted mixture of bran and sugar-cane molasses. The roasting must be carefully controlled in order to obtain the optimum flavor. The color of the products is a very good index of the desired end point. In order to prevent the roasting process from continuing after the materials have been removed from the roasters, they must be lowered in temperature rapidly; in the case of the roasted wheat, this is accomplished in a pan cooler, while the more sensitive bran-molasses mixture is passed through a shelf cooler. The wheat is then ground and blended with the roasted molasses mixture to give the finished product.

Several changes simultaneously occur during roasting. These include dextrinization of the starch, caramelization of the sugars, increased acidity and solubility, and the development of flavor. The finished product yields about 40% of water-soluble extract.

In the preparation of Instant Postum, Postum Cereal is percolated with hot water;

⁴⁵ The process of making these mineral additions is covered in U. S. patent 2,166,797, July 18, 1939. Methods of incorporation of copper, manganese, and iron are involved in U. S. patent 2,239,543, April 22, 1941.

⁴⁶ U. S. Patent 2,275,565, March 10, 1942, covers these additions.

⁴⁷ P. P. Pratt, *Trans. Am. Soc. Mech. Eng.*, 53, No. 4, 49 (1931).

the percolate is clarified, concentrated *in vacuo*, and finally dried in steam heated, vacuum drum driers (Fig. 102). The dried extract is obtained in the form of sheets

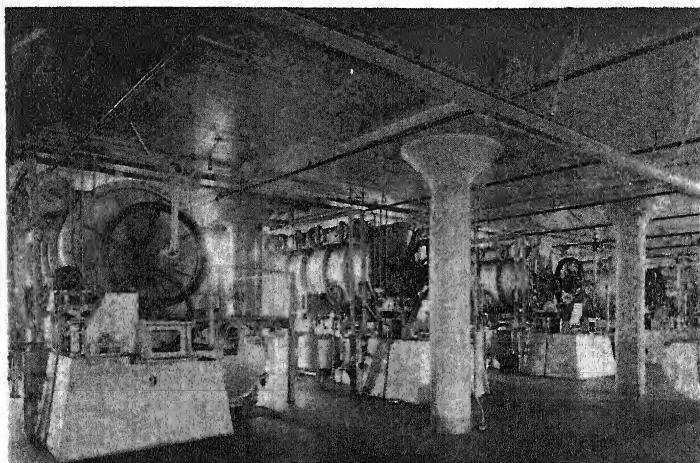


Fig. 102.—Manufacture of *Instant Postum*. Vacuum drum driers in which the concentrated liquor from the triple effect evaporators is dried. (Figs. 102 and 103 courtesy General Foods Corp., Battle Creek, Mich.)

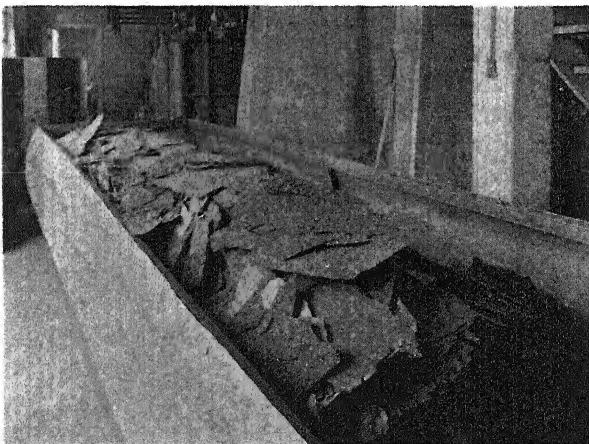


Fig. 103.—Manufacture of *Instant Postum*. Sheets of the dried product, as obtained from the vacuum drum driers.

of a brown crystalline-like substance (Fig. 103). These sheets become brittle when cold and are then ground to the required fineness and packed in tins of various sizes. The packing room must be maintained within narrow limits of temperature and

humidity in order to maintain the moisture content of the product at a sufficiently low level to prevent it from adhering to the containers and packing machinery.

The proximate composition of Postum Cereal and Instant Postum is given in Table 145 on page 680, Volume I.

X. COTTONSEED, PEANUT, AND SOYBEAN FLOURS^{47a}

In the development of acceptable edible flours from these sources, much scientific and technological research was required. Heat treatment is essential to reduce the moisture, improve the flavor, and inactivate the enzymes which otherwise would cause rapid deterioration upon storage. Moreover, cottonseed contains a toxic pigment, gossypol, $C_{30}H_{30}O_8$,⁴⁸ which must be destroyed by heat treatment; and soybeans require heat processing in order to increase the biological efficiency of the proteins as well as to remove the disagreeable "beany" taste. Many patent processes, which have been reviewed by Bailey, Capen, and Le Clerc,⁴⁹ have been developed for debittering soybeans. Nearly all the methods involve some form of heat treatment. The first successful process, described by Berczeller in 1924 (U. S. Patent No. 1,509,076), consisted in treating the cleaned soybeans with saturated steam for 10 to 15 min. A further development of this process (British Patents No. 367,865, Feb. 25, 1932; and No. 393,146, June 6, 1933) involve subjecting the beans to steam distillation. After this treatment, the beans are given adequate aeration, which further removes the beany odor and flavor. Other processes which have been developed include various methods of extracting the disagreeable principles with water, formaldehyde solution, dilute acids, etc.

At present the oil is extracted from the cottonseed and peanut by the hydraulic press method, whereas the more recently established soybean industry has developed around the expeller and solvent extraction methods. In pressing oil by the hydraulic and expeller methods, the decorticated seeds are given a more or less extensive heat treatment in order to facilitate the pressing process. This heat treatment darkens the color and causes destruction of significant quantities of thiamine. It is therefore necessary to establish conditions which would result in the maximum of desirable changes with the minimum of undesirable effects. This requires a compromise between overheating, with deterioration in color and loss of thiamine, and undercooking, which decreases oil yield and makes the further processing of the press cake into flour more difficult. In the case of the solvent extraction process, the necessary heat treatment is independent of the oil extraction operation, and the optimum treatment can be given without any concern about reduced oil yields; this process also readily permits the manufacture of products with a wide range in fat content and physical properties. Another problem was the difficulty in sizing the ground press cake. Bolting methods, as used for wheat flour, were rather unsatisfactory because the flour clogged the open-

^{47a} The author is indebted to J. W. Hayward, Archer Daniels Midland Co., Minneapolis, Minn. for valuable suggestions in the preparation of this section.

⁴⁸ P. Karrer and E. Tobler, *Helv. Chim. Acta*, **15**, 1204 (1932).

⁴⁹ L. H. Bailey, R. G. Capen, and J. A. Le Clerc, *Cereal Chem.*, **12**, 441 (1935).

ings in the silk bolting cloth. This difficulty was successfully overcome through the use of mechanical air separators which float the fine flour fraction from the coarsely ground particles by means of an air stream.⁵⁰

Cottonseed and peanut flours are partially defatted products but, for the soybean, three general types of flours are produced: "full-fat," "medium-fat," and "low-fat" flours. In manufacturing the full-fat soy flour, no fat (oil) is removed; the cleaned, dried, dehulled beans are cracked and heat processed to "debitter" and to increase the biological value of the proteins; the processed beans are then cooled and ground, and the flour obtained by air separation. Medium-fat flours are produced by partial removal of the oil by either the expeller or solvent extraction methods, whereas, in the low-fat flours, the oil is extracted by the solvent process. These methods of oil removal have recently been given by Goss⁵¹ and Markley and Goss.⁵² In the expeller process of oil removal, the cleaned, dehulled, cracked, dried soybeans are normally heat treated at 270° F. for about 13 min. and then passed through the expeller, where they are exposed to a temperature of 283–302° F. for about 3 minutes. When the meal is to be processed into flour, however, the expeller screw is water cooled, thereby lessening the discoloration of the meal and the destruction of the thiamine. The expelled chips are then cooled and ground by hammer-mill, and the flour obtained by air separation. In the continuous solvent process, the cleaned, dehulled, cracked beans are subjected to a mild heat treatment of about 115° F. for 10 min. and then flaked in order to give a maximum surface for extraction with the solvent. After extraction of the oil to the desired level, the extracted flakes are freed of solvent by "drying" at about 208° F. for 10 min. and then subjected to a heat treatment to produce a debittered product with optimum nutritional properties. The flakes are then aerated and cooled, and ground to a fine flour. In addition to flour, edible soybean meats, grits of various sizes, and flakes are also produced.⁵³

⁵⁰ D. S. Payne, *Chem. Eng. News*, 20, 1173 (September 25, 1942).

⁵¹ W. H. Goss, *Soybean Digest*, 1 (8), 2; (9), 2; (10), 4 (1941).

⁵² K. S. Markley and W. H. Goss, *The Chemistry and Technology of the Soybean and Its Derived Products*. Part II, Bur. Agr. Chem. Eng., U. S. Dept. Agr. Mimeographed publication ACE-142.

⁵³ A. M. Dickson, *Soybean Digest*, 2 (11), 7 (September, 1942).

Chapter XVI

THE PRODUCTION OF BREAD AND BAKERY PRODUCTS

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This chapter deals with production methods as used in large bakeries, that is, machine production. Hand methods of production are used only in small retail bakeries; and, since such bakeries produce a relatively small percentage of all bakery products, these methods are not considered.

Formulas are not given for various bakery products. Basic formulas for various bakery products from which individual products can be developed are given in Chapter XVIII, Volume I. Also, any formulas given would be personal preferences and would undoubtedly have to be changed to meet the requirements of others. In addition, formulas are available from most bakery ingredient suppliers in voluminous quantities; thus, any that could be added here would be superfluous and not deserving of the space required.

The production methods used are classified according to the type of product. These are as follows: bread, rolls, sweet yeast-raised products, crackers, cookies, cakes, and doughnuts. The production of each one of these products will be discussed separately.

I. STORAGE OF INGREDIENTS

The problem of ingredient storage in any type of bakery is of vital importance. Flour, sugar, salt, dry milk, other dry ingredients, wrapping papers, and shortenings should be stored at temperatures around 65 to 75° F., in clean, light, well-ventilated rooms. This is particularly necessary in flour storage, since flour for bread production needs a short period of aging in such a room before it will produce the best quality bread. This is the case even though the flour has been treated properly with bleaching and maturing agents at the mill. The proper storage of flour is illustrated in Fig. 104. The flour is stacked on skids so that the stacks can be moved readily. Refrigerated rooms are necessary for the storage of liquid milk, yeast, eggs, fruits, and similar ingredients.

The size of the storage problem in any plant is generally in proportion to the quantity of ingredients carried on hand. The more rapid the turnover of ingredients, the simpler is the storage problem.



Fig. 104.—Flour storage room in an Eastern bakery. Windows in the background are "blacked out" because of war regulations.

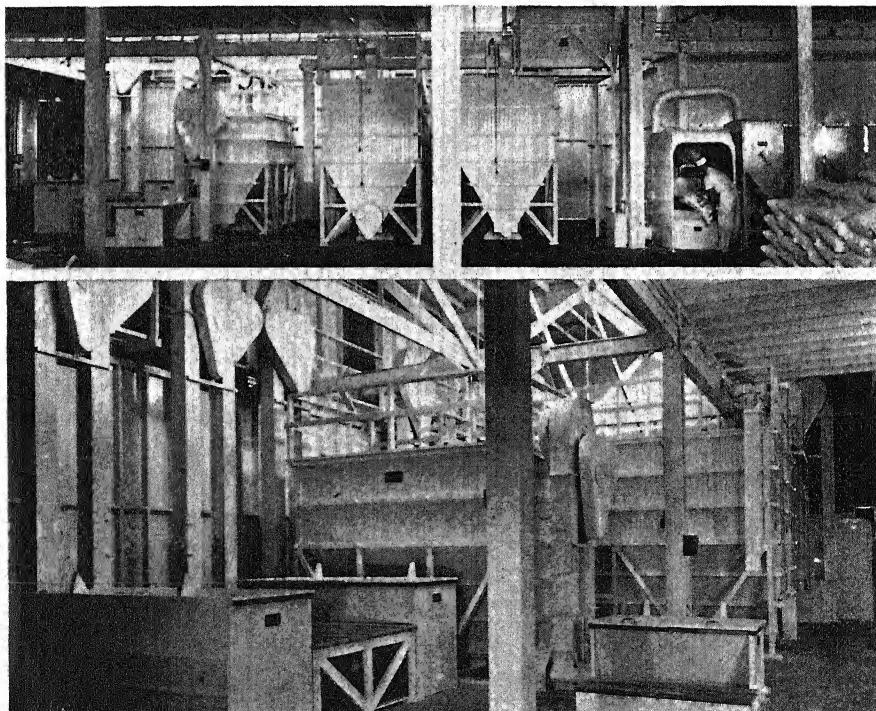


Fig. 105.—Typical flour handling equipment for a bakery

II. BREAD PRODUCTION

The principal ingredient in bread is flour. Thus, special equipment is utilized for handling the large volume of flour that must go into every batch of bread. A typical example of flour handling equipment is shown in Fig. 105. After the flour is dumped (top of picture), it is automatically carried to the hopper above the mixer, and at this point is sifted and automatically scaled directly into the mixer. A bin is generally provided for each mixer. The amount of flour going into the mixer depends on the size of the mixer. Those illustrated in Fig. 106 handle 600 pounds of flour per batch. If dry or condensed milk, as is usually the case, is used in the mix, then a considerable portion of water must be added. This is handled through automatic water scaling

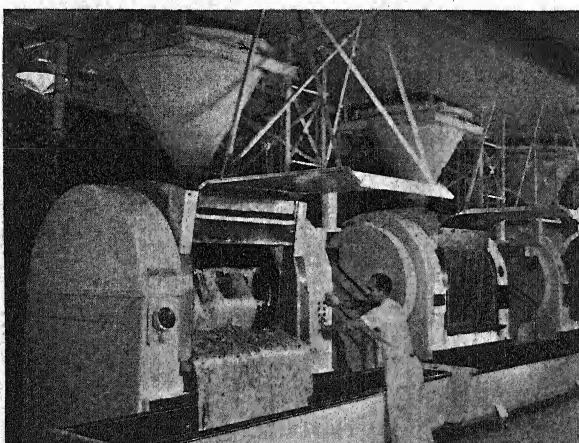


Fig. 106.—Battery of modern bread dough mixers.

equipment. See Fig. 107. The other ingredients which have been weighed in proportion to the quantity of flour, that is, sugar, salt, yeast, etc., are added through the top of the mixer. The yeast is broken up in an emulsifier, also illustrated in Fig. 107. As with the water, the yeast is piped directly from the emulsifier into the mixer.

Although the order of incorporation of many of the ingredients varies in different plants, the general procedure is to dissolve the salt, sugar, yeast food, and milk in part of the ingredient water and add it to the other ingredient water already in the mixer. The flour is drawn in and the yeast solution from the emulsifier is then added. The shortening is added after the dough has been partially mixed.

Modern mixers are equipped with several devices to facilitate the mixing period: an automatic timing device so that the mixer will stop after a predetermined time; a temperature indicator so that the temperature of the dough can be determined at any point of mixing; and a water jacket around the mixing bowl to cool the dough during mixing. The circulation of cold tap water around the water jacket is not sufficient to keep the dough cool. There is so much heat generated during the mixing period that

water at about 35° F. is circulated through the water jacket. The water is automatically controlled, and is cooled by means of freezing coils. The amount of refrigeration at the mixer is controlled by the rate of circulation of the water or by the temperature of the water circulated. It must be adjusted so that the sponge is mixed at 74 to 76° F. and the dough at approximately 78 to 80° F.

The total amount of water added to the mix depends upon the flour used and on the quantity and kind of the other ingredients. It must be so adjusted that the correct consistency of the dough is obtained. The consistency is dictated by the other machines through which the dough must pass later. If the dough is too stiff or too soft, it will not pass through these machines.

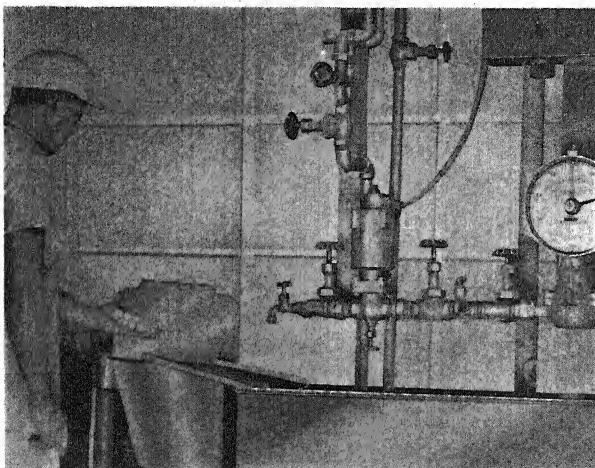


Fig. 107.—Water meter (at right) and emulsifier (at left).
The operator is adding enrichment tablets to the emulsifier.

The purpose of mixing is to bring about an intimate and uniform mixture of the ingredients. The result should be a smooth glutinous mass, as complete as possible a wetting of the starch and hydration of the gluten, and mechanical development to an extensible and pliable dough. An undermixed dough will produce bread that is not uniform and is irregular in most of its qualities. If the dough is overmixed, the gas retaining properties will be injured and the loaves will have inferior grain and volume.

As soon as the dough is properly mixed, the door is lowered automatically and the dough thrown out into a lightly greased fermentation trough (foreground, Fig. 106) by the rotation of the arms of the mixer. The dough, weighing approximately 1000 lbs., is too heavy to be handled or taken out of the mixer by hand.

If the standard size of trough is employed, two feet of trough length should be used for a straight dough containing 100 lbs. of flour. In the case of a sponge, four feet of trough length should be allowed for a sponge containing 100 lbs. of flour. If the trough space allowed is too great, the dough will spread out instead of rising properly. If it

is too small, the dough or sponge will rise up to the top and overflow onto the floor. In fact, it is said that the "punching" or cutting over of straight doughs resulted as a measure to prevent them from overflowing the troughs.

The dough in the trough is then wheeled to the fermentation room and left for the proper length of fermentation. The room is controlled at approximately 80° F. and a relative humidity of 75%. Air circulation in the room is kept at a minimum in order to prevent crusting of the doughs. A typical fermentation room is shown in Fig. 108. The troughs are filled with sponges ready to be taken back to the mixer. The scale at the right is used for weighing sponges and doughs.

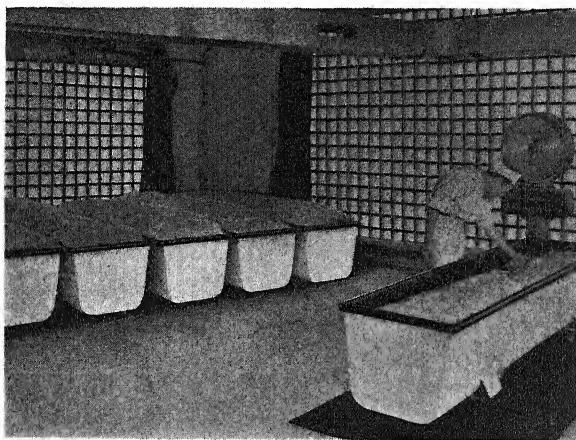


Fig. 108.—A typical fermentation room. The curtains in the background are black-out curtains.

If a sponge were being handled, after the proper predetermined fermentation time, the sponge would be cut up into pieces and put back into the mixer. The remaining ingredients would be added, that is, those that were not put into the sponge mixture, and the dough mixed for a definite period of time, exactly as the sponge was mixed. The dough formed by the remixing would be taken back to the fermentation room and allowed to ferment for a brief period, generally, 15 to 45 minutes.

Fermentation starts as soon as the sponge or dough is set, and continues until the dough reaches the oven and the temperature of the oven kills the yeast and inactivates the enzymes. However, in the bakery, fermentation is generally considered to take place only to the point at which the dough is taken from the fermentation room. During fermentation, the enzymes condition the dough so that it will be in the proper state for retaining the maximum amount of gas when it reaches the proof box and the mouth of the oven. The length of fermentation depends upon the type of flour being used and the quantities and kind of other ingredients.

After fermentation, the dough is then ready to be divided into small loaf size or one-half loaf size pieces (18 oz. for 16 oz. finished loaf). This is accomplished by means of

a divider as shown in Fig. 109; the dough pieces just dropped from the hopper can be seen on the moving belt. If the straight dough procedure is employed, there is no re-mixing period and the dough is taken directly from the fermentation room to the divider. If the fermentation room is on the same floor as the divider, a dough hoist is used to lift the dough into the hopper of the divider, that is, the top part of the divider. However, often the fermentation room is on the floor above the divider so that the dough can be sent through a chute directly into the hopper of the divider.

After the dough is cut up in small pieces by the divider, each piece is individually rounded up so as to form a skin over the dough and thus retain gas during subsequent fermentation. A rounder that is used for this purpose is shown also in Fig. 109. The dough pieces coming from the rounder are handled individually, and allowed to pass through the so-called overhead proofer in a continuous chain, shown in Fig. 110. It takes approximately 12 minutes for the dough to pass through the overhead proofer, depending upon the speed of travel. This allows sufficient time for the dough to recover, that is, to generate further gas so that it is in condition to go through further machines.

After passing through the overhead proofer, the dough pieces are sent to a moulder (Fig. 110). The moulder squeezes the gas out of the dough and then rolls it up into an elongated cylinder. These cylinders are then placed into machine-greased pans in which the dough is to be baked. Dough placed in the pan as such produces bread that is called round top bread. If twist bread is to be produced, the dough pieces are made one-half the weight needed (same length), and two pieces are twisted together (3-4 twists, depending upon the length of the loaf) and the twisted dough panned. Another type of bread, known as cross-pan bread, is made by taking a single dough piece, cutting it into three or four lengths, depending upon the size of the pan, and then panning the dough pieces at right angles to the pan. The pans containing the dough are placed on racks and these racks put into a proof box, where the temperature is 94 to 98° F. and the relative humidity approximately 85%. Under these conditions, the dough ferments vigorously, and is allowed to remain in the proof box until it has reached approximately to the top of the pans. The height to which the doughs are proofed determines to a great extent the "lightness" of the bread. The pans are then taken to the oven and the dough baked.

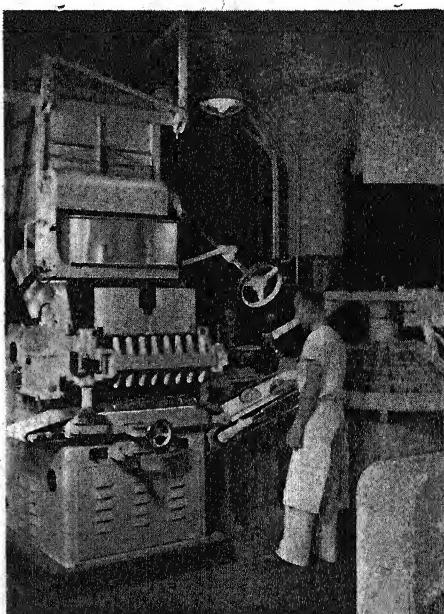


Fig. 109.—Divider (at left) and rounder

During the first few minutes of baking, the yeast functions very rapidly. However, the action is stopped when the dough reaches 140 to 150° F. At this temperature, the enzymes are inactivated and the production of gas ceases. During the first few minutes of baking, the dough expands approximately the same amount that it did in the proof box. This expansion is due to:

1. The rapid production of carbon dioxide by the yeast.
2. The release of carbon dioxide from solution produced prior to the oven stage.
3. The normal expansion (due to heat) of carbon dioxide and air trapped in the dough.

The expansion of the dough in the oven is stopped by the "setting" of the dough, that is, the baking of the dough.

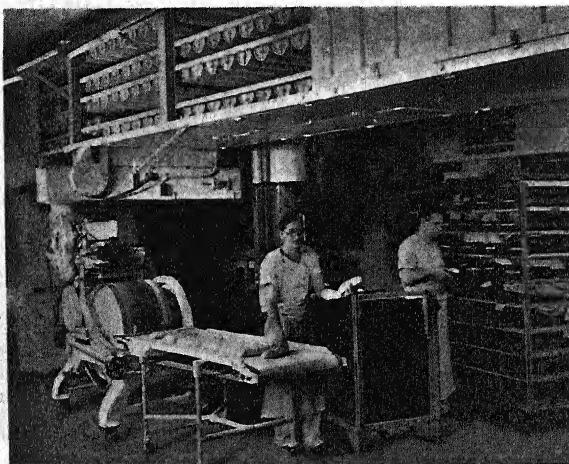


Fig. 110.—Moulder and overhead proofer (opened so that the individual pockets can be seen).

During baking, the dough loses the alcohol of fermentation and some moisture, the gluten and other proteins become coagulated, and the starch is partially gelatinized. Although the interior of the loaf does not reach temperatures above the boiling point of water, the exterior of the dough becomes much hotter and dextrins are produced on the outer surface of the dough, forming the crust. The golden-brown color is due mainly to caramelization of the sugars in the dough. In addition, during baking, all molds and disease germs are killed if they should happen to be present. In order to produce a glaze on the bread, steam is used during the first few minutes of baking. The temperatures employed for baking bread are from 450 to 500° F.

In general, two different types of oven are used. In one, the traveling plate oven, the dough is fed into one end and comes out at the other as finished baked bread; it travels through the oven on an endless belt. In the other, the revolving tray or double-lap type of oven, the dough is fed into the oven at the same point that the

baked bread comes out; the dough during baking travels to the back of the oven and then back again to the front. The picture in Fig. 111 is that of a traveling plate oven equipped with safety controls and fired with gas; the feeds to the individual gas burners

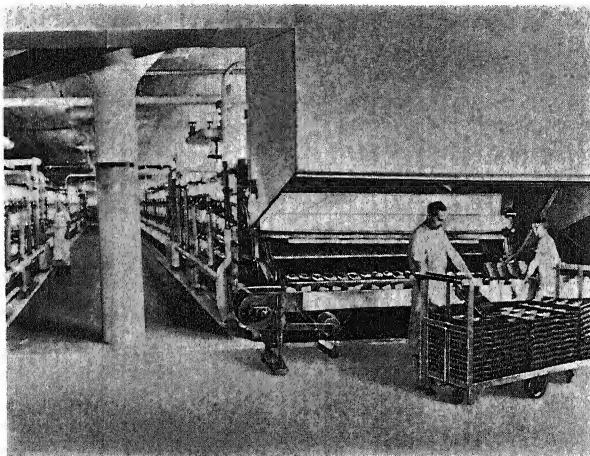


Fig. 111.—Traveling plate oven.

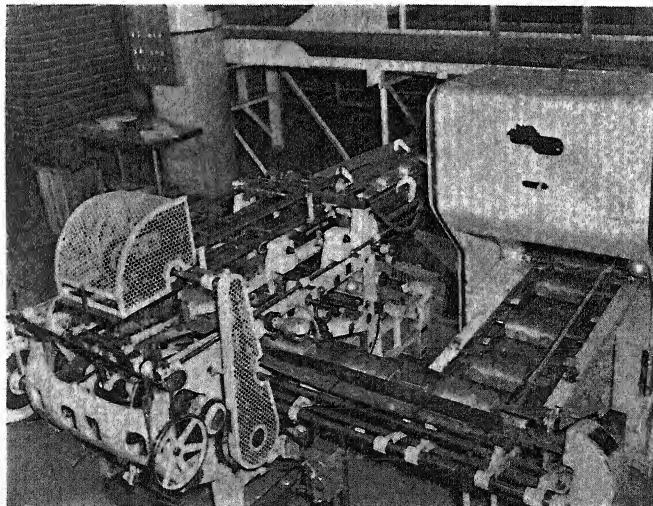


Fig. 112.—Slicing and wrapping unit.

are on the side of the oven; the bread can be seen coming out of the oven; the dough is fed in at the opposite end.

When the bread comes from the oven, it must be cooled before it can be sliced and

wrapped. The process of cooling generally takes 2 to 3 hours. Before wrapping, the bread should have an inside crumb temperature of no more than 85° F. The bread can be cooled in several ways:

- (a) It can be placed on racks and allowed to cool in the bakery atmosphere.
- (b) It can be taken by means of traveling belts back and forth in the bakery atmosphere until cooled. This method has an advantage over the first in that the bread need not be handled but can be sent directly to the slicer.
- (c) Racks of bread can be run through a tunnel type of cooler, that is, a room in which the temperature is controlled at about 70 to 75° F. and the relative humidity at about 85%. This prevents some loss of moisture during the cooling process.
- (d) The bread can be allowed to pass through a tunnel type of cooler on traveling belts. This has the advantage over method (c) of eliminating the handling of the bread; and the bread can be fed directly to the slicer.

After the bread is cooled, it is taken directly by a conveyor to the slicing and wrapping machine, where it is automatically sliced and wrapped. It comes out of the slicing and wrapping machine without having to be touched by human hands, and is fed directly by conveyor belt to the loading platform, where it is packed in baskets and loaded on trucks for distribution. Figure 112 shows a modern slicing and wrapping unit, the bread being sliced at the right and wrapped at the left.

Figure 113 shows a flowsheet of this complete bread production picture.

III. METHODS FOR OTHER BAKERY PRODUCTS

1. Rolls

Plain rolls, such as sandwich rolls, Parker House rolls, etc., are made in a similar manner to bread up to the point at which the dough is divided into small pieces. The dough must be mixed and fermented in the same way as bread. It is a somewhat richer dough than bread in that it contains more sugar and shortening and may contain more milk. The dough, instead of being placed in a divider, is fed into a so-called roll machine. An example of a continuous operation roll machine is shown in Fig. 114. This is really a divider and rounder combined. The dough is divided by the machine (foreground, Fig. 114) into small individual roll units, which are then rounded up on the small rounder to get a skin on them and, by means of a conveyor belt, are passed to operators (background, Fig. 114) who place them on pans. After the rolls are panned, they must be proofed in the same way that bread dough is proofed, and are then baked. They are generally baked in the same oven in which bread is baked, but at 390 to 410° F. After baking and cooling (the same as with bread except for a much shorter time), the rolls are ready for packaging. After they have been placed in trays by operators, the trays are wrapped by machine.

2. Sweet Yeast-Raised Products

Whether sweet yeast-raised products are small units such as sweet rolls, or larger units such as coffee cakes, there is no difference in the process of manufacture, ex-

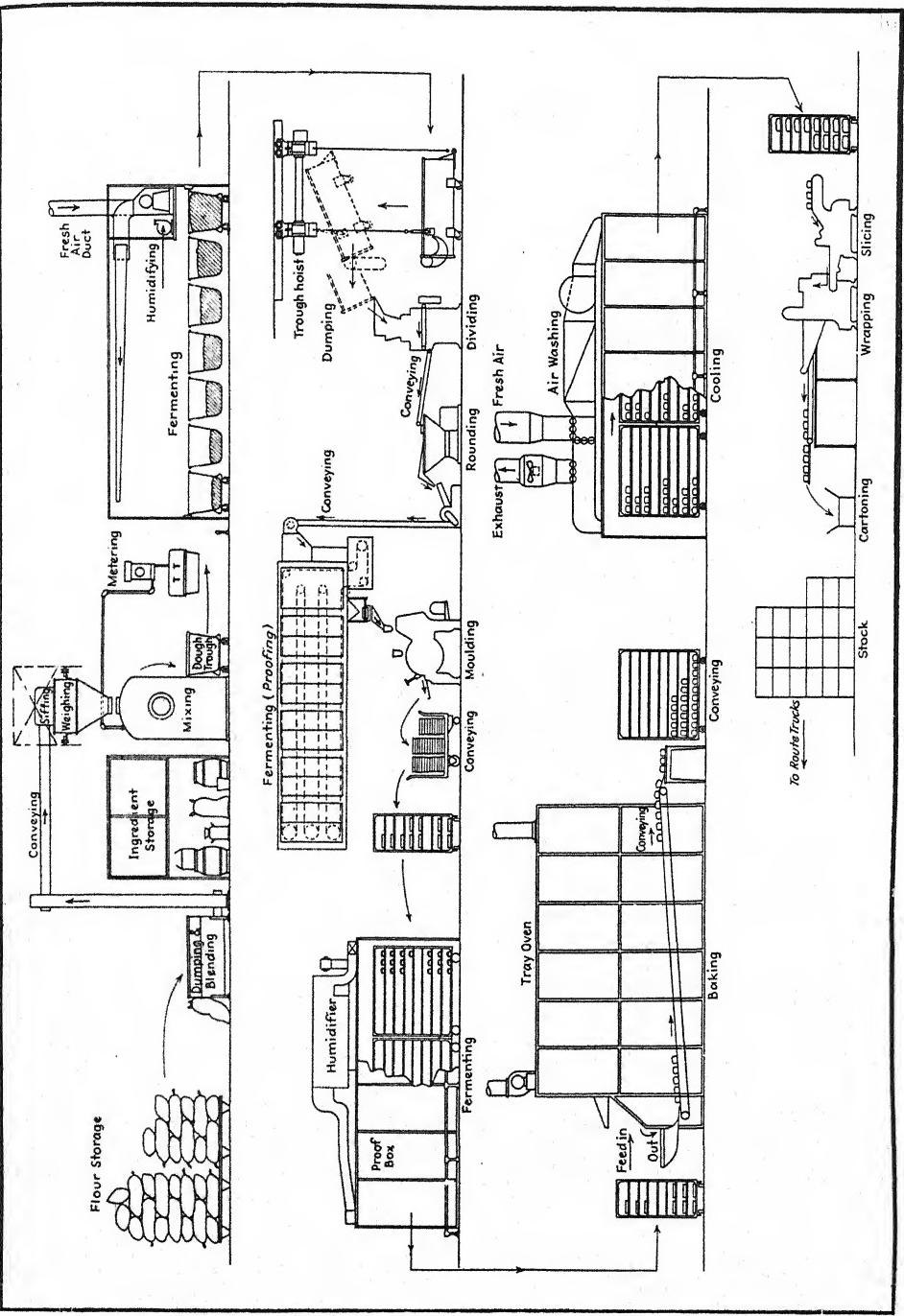


Fig. 113.—Flowsheet for modern bread bakery. (Courtesy Food Industries.)

cept for the size of the product being baked. Sweet yeast-raised merchandise is generally manufactured by the straight dough method. After the dough is mixed and fermented, it is ready for dividing into units and finishing in the proper shape. The manufacture of sweet rolls and coffee cake has generally been a hand operation in the past. However, in recent years many bakeries have converted this into a mechanical procedure, especially for the manufacture of coffee cake.

After fermentation, the sweet dough is divided into the proper size for the specified weight of the coffee cake by putting it through a bread dough divider. After the divider, the dough is rounded, allowed to rest and then put through sheeting rolls

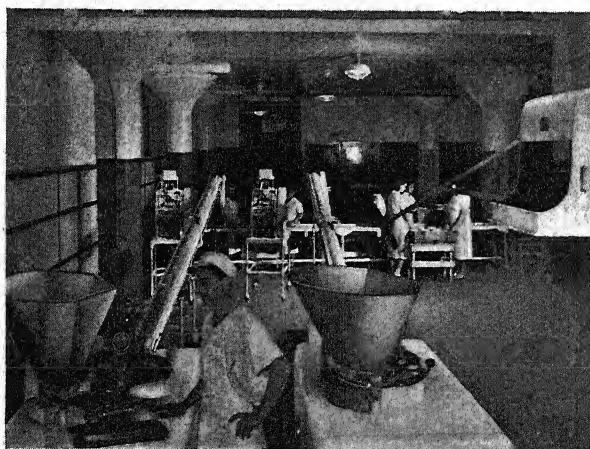


Fig. 114.—A complete modern roll operation.

that give it the flatness necessary for further processing. The processing that follows depends upon the type of goods to be made. In order to meet heavy week-end production, the dough at this point may be put into a refrigerated box, where the temperature is kept at approximately 35° F. and the relative humidity at 95%. The dough may be kept in this form for several days, and then taken out, warmed up to room temperature, and processed.

When the dough is taken from either the sheeting rolls or from the refrigerated box, it is placed on the make-up conveyor where some hand operation must be performed, the amount depending upon the type of coffee cake to be produced. The dough is rolled to the right size by one operator, and filling, if any, is then added from a hopper on the conveyor belt. The next operator folds the dough into the proper shape. In cases where such products as individual cinnamon rolls are to be produced, the dough is cut mechanically into the proper number of pieces as it moves along the belt. These are then panned by hand and sent to the proof box. The procedure of rolling the dough, making it up, and cutting it is shown in Fig. 115. The divider and rounder of the dough are seen in the background to the right; after rounding, the dough is car-

ried on a belt to the sheeting rolls in the right foreground; the doughs are rolled up while moving and are cut into individual cinnamon rolls, in this instance, by the

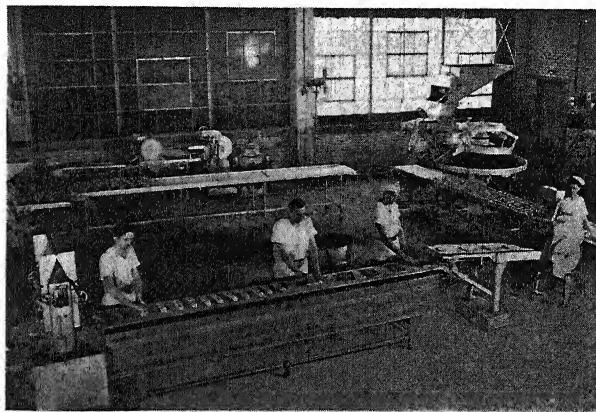


Fig. 115.—Sweet yeast-raised dough make-up.

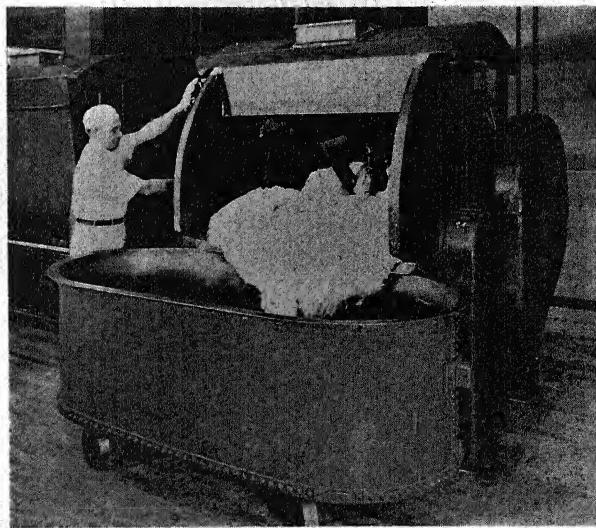


Fig. 116.—Modern mixer used for cracker doughs. (Courtesy National Biscuit Company.)

machine in the left foreground. The products are then proofed in the proof box just as bread is proofed, and then baked.

They can be baked in ovens just like those used for bread. However, the temperatures employed are generally somewhat lower. Coffee cakes are generally baked at

approximately 410 to 440° F. After baking, the products are cooled and immediately sent by conveyor belts into mechanical wrapping machines which wrap the products automatically. The wrapping machine employed can be the same as that used for wrapping roll packages. The baked products are then ready for delivery.

3. Crackers

Crackers, like bread, are generally produced by using the sponge and dough method. The doughs are mixed in similar machines and handled in a similar manner to bread (see Fig. 116). The sponges and doughs are, however, made more stiff. After the sponge has been fermented, remixed into the dough, and the dough fermented, the

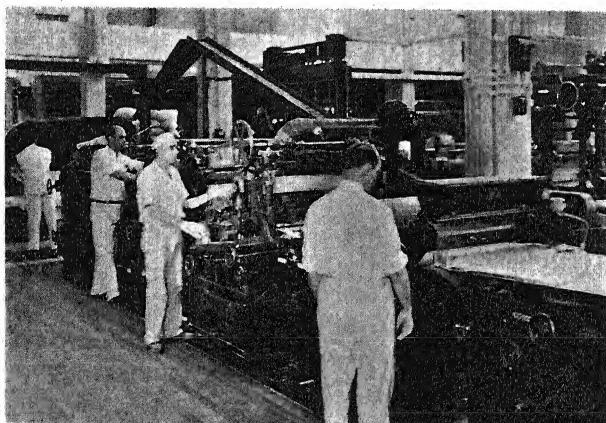


Fig. 117.—Sheeting and cutting of cracker dough. (Courtesy National Biscuit Company.)

dough is rolled out into a long, continuous sheet of definite width and thickness. This continuous sheet of dough passes through a cutting machine which cuts it into the shape of cracker desired. The shape can be changed by simply changing the dies of the machine; thus, various shapes and sizes of crackers can be produced on the same machine. This complete sheeting and cutting operation is shown in Fig. 117; the dough is fed in at the left and comes out at the right foreground as completely shaped crackers. The cut dough is then fed into continuous band ovens in which the crackers are baked (Fig. 118). The band oven is similar to the traveling oven used for bread except that it is much smaller. The crackers emerge from the opposite end, baked. Crackers are baked at temperatures from 500 to 525° F. After cooling, they are packaged, generally in cartons, and the cartons wrapped. They are then ready for delivery.

4. Cookies

Cookies are mixed in a similar manner to crackers, since a stiff dough is to be produced. However, they are chemically leavened doughs instead of yeast leavened doughs. After the cookie dough is mixed, it is cut up into the proper shapes and sizes by means of a so-called cookie machine. This machine is similar to a dough divider. It divides the dough, and deposits it from dies. Such a machine is shown in Fig. 119. It does not cut the cookies out of a sheet as in the case of crackers. The cookies are dropped from the machine onto metal cookie sheets passing underneath on a traveling belt. The cookie sheets are fed directly into the oven for baking. Cookies can, however, be handled like crackers, that is, cut out upon a continuous traveling sheet that is

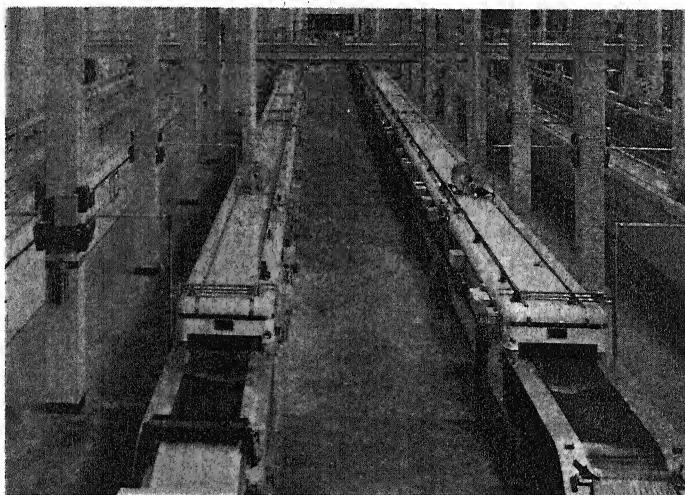


Fig. 118.—Traveling band ovens equipped with the latest safety devices. Each unit is over 800 ft. long. (Courtesy National Biscuit Company.)

fed directly into a band oven. This gives better continuous flow by mechanical action, and less handling is needed. The temperature at which cookies are baked varies from 350 to 425° F. The cooling and packaging of cookies are similar to those of crackers. Sometimes cookies are coated with chocolate and other icings. An example of a chocolate enrober is shown in Fig. 120. Cookies at the extreme right are entering a cooling unit.

5. Cakes

The mixer used for incorporating the ingredients in a cake batter is different than that used for any of the foregoing products because, for cake batters, the mixer must beat in a certain quantity of air, and also must produce a stable emulsion of the various ingredients. A modern type of cake mixer is shown in Fig. 121. The mixer at the

right, showing the wire whipping attachment, has just finished mixing a batter; the one at the left is in the process of mixing a batter; automatic water scales can be seen in the background between the mixers. The ingredient handling equipment, such as

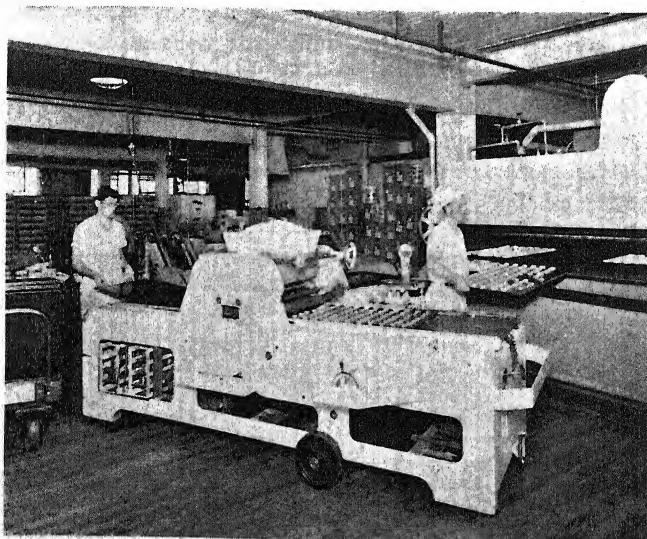


Fig. 119.—Die-cut cookie machine.

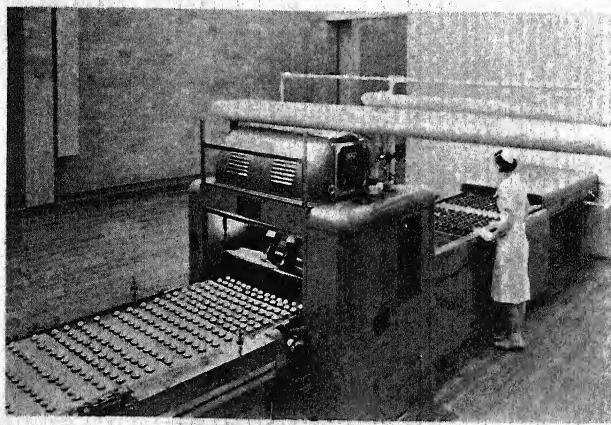


Fig. 120.—Chocolate enrobing machine for cookies. (Courtesy National Biscuit Company.)

flour handling, the automatic flour scale, the automatic water scale, etc., is similar to equipment used for bread. The cake mixer, however, is not equipped with a water jacket. The temperature of the mix being made can be controlled by the tempera-

ture of the water and the temperature of the eggs being used in the mix. Most cake batters such as angel food, pound cake, and layer cake should be mixed cool. However, sponge cake batters should be mixed warm, that is, at approximately 90° F. The

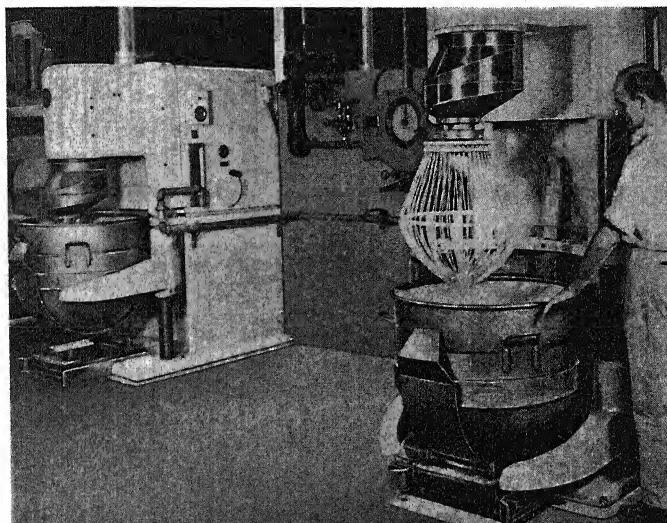


Fig. 121.—Modern cake mixers.

same mixer can be used for all these various types of cakes. However, the agitator is changed in some cases. For example, in the case of angel food and sponge cakes, a wire whip (Fig. 121) is used; in the other cakes, generally a paddle or beater-type attachment is used. The cake mixer is equipped with timing devices just as in the bread mixer.

After the cake batter is mixed, the bowl is removed from the cake mixer and transferred to a depositor, where the bowl itself is lifted by means of a mechanical hoist to the top of the depositor and dumped. The hoist and depositor are shown in Fig. 122. The depositor automatically deposits the proper quantity of batter in the cake pans as they are passed underneath. By means of different separators in the depositor and the use of different types of dies, batter can

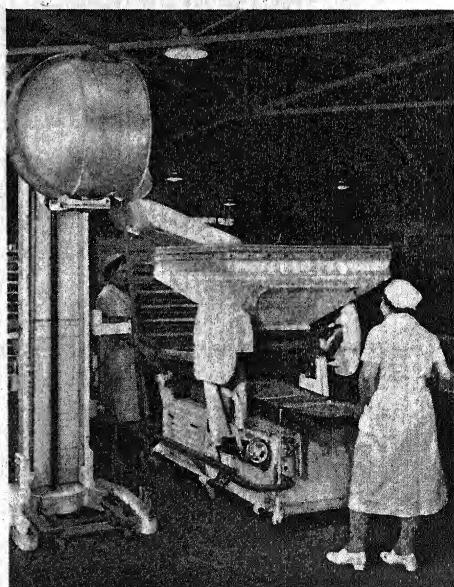


Fig. 122.—Hoist and depositor.

be deposited in all shapes of pans. Also, two different types of batters can be deposited in the same pan, for instance, in the production of marble pound cake.

The pans with the batter deposited in them are placed on racks as they come from the depositor and taken to the oven where they are baked. Handling can be eliminated by automatically conveying the pans with batter directly to the oven on conveyor belts. The ovens used for cake baking are the same type as are used for bread; different temperatures, however, are required for different cakes. In general, the temperatures used for baking cake are lower than those for baking bread, ranging from 300 to about 430° F. The baking time will vary from 10 minutes to 3 hours, depending upon the type of cake, its size, and its shape. If the correct temperatures are not

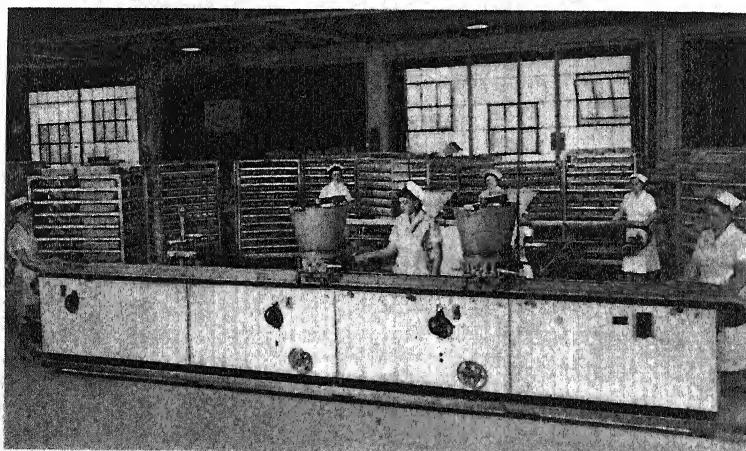


Fig. 123.—Icing machine in operation.

used, inferior quality merchandise will be produced. For example, excessive oven heat produces a thick, hard crust and may even cause a burst on the crust due to too rapid an expansion of gas in the cake. This also produces inferior grain and texture. Too low a baking temperature means too long a baking period and results in a dry eating cake. This means poor eating and keeping quality and generally a thick crust and coarse grain. In general, fruit cake and pound cake are baked at temperatures from 300 to 340° F., layer cakes from 350 to 400°, and angel food and sponge cake from 370 to 420°. These temperatures are only approximate and depend upon the size of the cake in question.

A double-lap cake oven is fed and unloaded at the same end. After the cakes are baked, they are cooled in a manner similar to that for bread. They are generally cooled on racks; however, the conveyor belt method can be employed.

The icing of cakes requires some handwork; this is particularly true of the round cakes. Rectangular-shaped cakes can be handled by machine. The icing machine (see Fig. 123) is quite similar to the depositor in that it simply deposits a sheet of icing

on top of the cake. By special adjustment, this and similar machines can be used to deposit jelly on sponge cakes for the production of jelly rolls, and for similar operations. In Fig. 124, sponge cake is being carried by a conveyor from the ovens at the left; the cake is transferred from the pans to the jelly depositor and then on to a moving conveyor belt, where the jelly is smoothed out and the jelly roll rolled into shape.

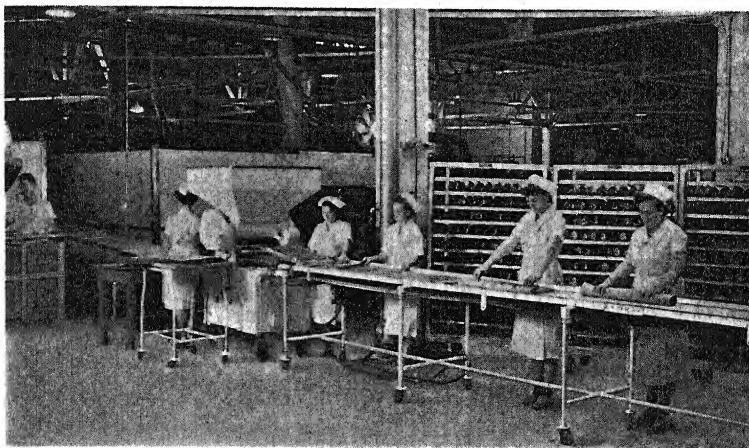


Fig. 124.—Jelly-roll operation.

If the cakes are iced, the icing is allowed to dry for a short time and the cakes are then wrapped. The wrapping is done by a machine similar to the bread wrapping machine or the doughnut wrapping machine.

A flowsheet for cake production is shown in Fig. 125.

6. Doughnuts

The following description of doughnut production is based entirely on cake doughnut types. Yeast-raised doughnuts are not considered because the majority of all doughnuts produced are cake types.

The mixing of doughnuts is similar to that of cake, particularly pound cake. A paddle type of beater is used for the purpose. The batter should be between 70 and 75° F. when mixed. It is all-important that the temperature of the batter be just right. If the batter is too warm, the doughnuts may lack volume and be misshapened and not of the proper weight. This is mainly due to the fact that the batter does not go through the cutting machines properly. If the batter is too cold, the doughnuts will generally stay under the fat too long after dropping and will fry too slowly during the first few minutes they are in the fat.

After the batter is mixed, the mixing bowl is taken up by means of a hoist and the contents dumped into the doughnut machine, an example of which is shown in Fig. 126. The batter is forced by means of air pressure, at approximately 2 lbs. per sq. in.

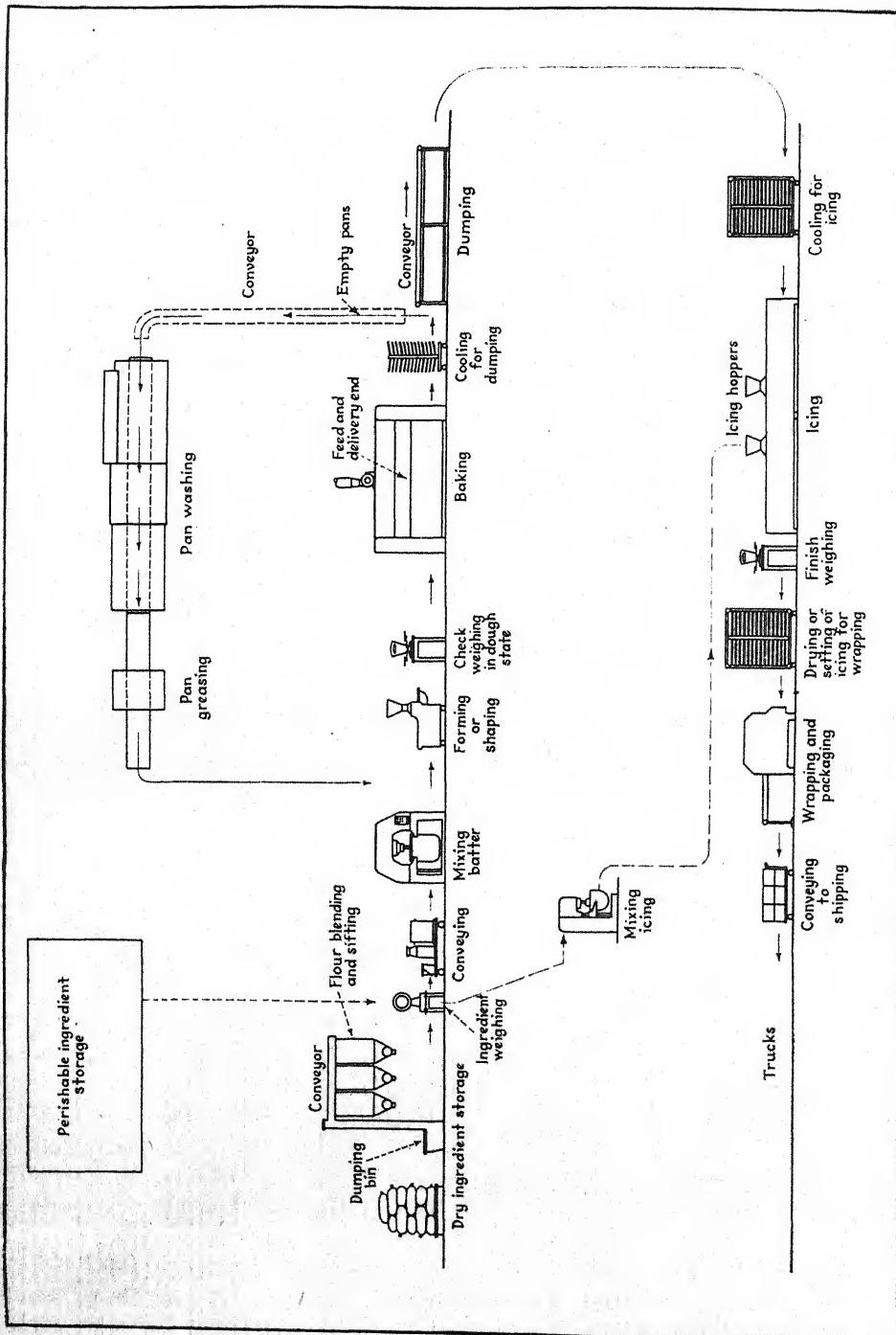


Fig. 125.—A flowsheet for modern cake baking. (Courtesy Food Industries.)

(in most machines the consistency of the batter is considered proper when the air pressure necessary to expel the batter is 2 lbs. per sq. in.), through a so-called doughnut cutter, which cuts and drops the doughnuts into the frying fat, the temperature of which is automatically controlled between 370 and 380° F. The doughnuts are then carried along automatically and turned when half fried.

Although various bakers believe that different amounts of fat absorption are permissible, the average opinion is that the fat absorption should be between 2 and $2\frac{1}{4}$ oz. per dozen doughnuts (where each doughnut weighs approximately one ounce). Excessive fat absorption is generally due to overmixing of the batter, having the

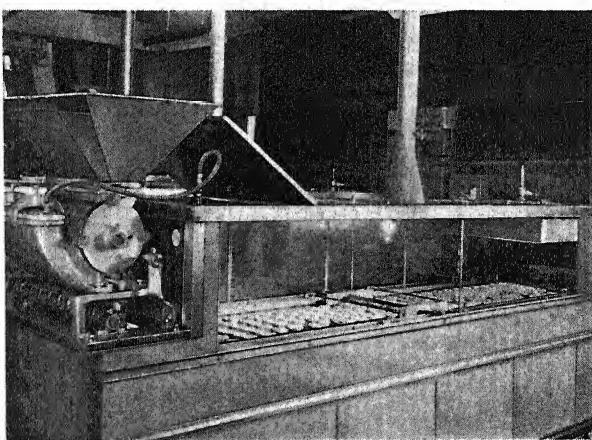


Fig. 126.—Doughnut frying machine.

dough batter too hot or too cold, having the frying fat too hot or too cold, and not turning the doughnuts promptly after they have fried on one side. The absorption of fat should not be excessive, for if this is the case the doughnuts will be "greasy." If the absorption of fat is not sufficient, the doughnuts will have poor keeping quality.

At the end of the frying period, the doughnuts automatically go out onto a moving conveyor belt and are taken to the doughnut cooler. The doughnuts move through the cooler on continuous belts, the temperature and humidity of the cooler being controlled by the movement of air through the cooler. Often there is no other control of temperature and humidity than simply the movement of air through the cooler. However, it is preferable to have the temperature controlled at approximately 70 to 75° F. and the relative humidity at approximately 85%. When the doughnuts are to be sugared, this control is of vital importance, for, if the doughnuts are too dry, they will not "absorb" sugar on the surface.

After the doughnuts come from the cooler, they are conveyed either directly to the packing table or through sugaring machines. The sugaring is accomplished by the continuous rolling of and sifting of sugar onto the doughnuts.

The sugar added to the doughnuts is a special preparation: it is powdered sugar containing flour and fat in order to prevent it from dissolving rapidly after being applied to the doughnuts. Dextrose is much more adaptable for this purpose than is sucrose.

The doughnuts are packed into cartons and sent through the wrapping machine. In comparison with most operations in the bakery, the doughnut operation is relatively simple and is one of the easiest to streamline and to handle entirely mechanically.

Chapter XVII

SUGARS AND SIRUPS

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Brooklyn, New York

I. SUGARS

The principal sugar used throughout the world is sucrose. About 30,000,000 tons are produced each year, and of this total about 65% is derived from the sugar cane and about 35% from the sugar beet. The countries producing large quantities of sugar from sugar cane are India, Java, Cuba, and the Philippines. Lesser quantities are produced in Hawaii, Brazil, Japan, Puerto Rico, and the United States. The principal countries producing beet sugar are Germany, Russia, the United States, and France.

Sucrose is actually not manufactured. The factory simply recovers the substance produced by the plant. This recovery process consists essentially of extracting the juice from the plant, treating the juice so that the sucrose may be crystallized from it, and refining the sucrose crystals produced.

1. Cane Sugar

Briefly, in the case of cane sugar, the juice is extracted by milling or squeezing the cane between rollers. In order to clarify the juice, it is treated with lime, sulfur dioxide, carbon dioxide, or phosphates and heat. In this treatment, certain components of the juice are coagulated and precipitated, and the precipitate is permitted to settle by sedimentation. After decantation, the clarified juice is concentrated by evaporation in stages. The first stages produce a syrup which contains from 45-55% sucrose. The remaining stages continue the evaporation under such conditions that the sucrose crystallizes. The crystals are then separated from the mother liquor by centrifuging.

The raw sugar produced by the foregoing processing is generally shipped to refiners in the United States and Canada or to Europe. In order to be refined, the raw sugar is washed, redissolved, neutralized with lime, filtered by pressure with the addition of filter aids, decolorized with bone black, refiltered, concentrated by evaporation, crystallized, separated, graded, and packed.

It is clear that these processes are variations of the unit operations discussed in Chapters I and II of this volume.

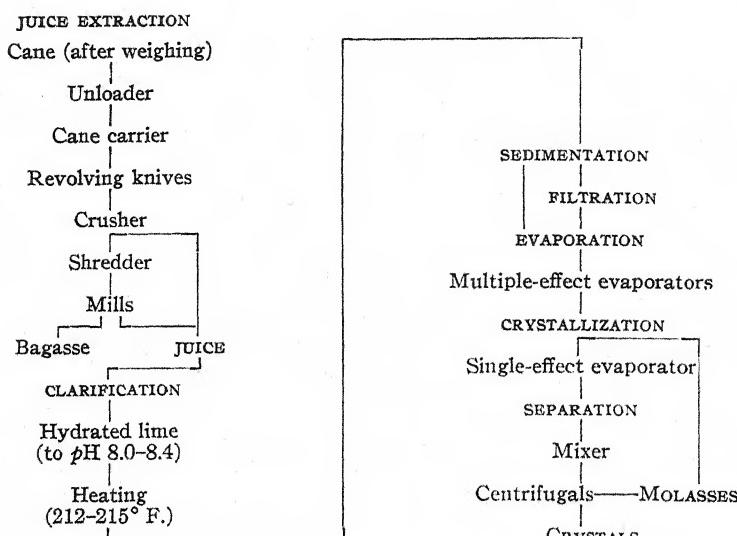


Fig. 127.—Cane sugar manufacture.

(a) Raw Sugar

After the cane is cut in the fields, it is brought to the plant by railroad or truck, or even by carts drawn by mule and oxen. The cane is generally unloaded mechanically by revolving cranes, traveling cranes, endless chains, or reciprocating rakes. Modern machinery permits a more even depth of cane to be fed to the mill with a resulting increase in efficiency. Formerly, manual labor was used to achieve this result. The unloader feeds the cane directly to the cane carrier or to a feed table or side carrier. This diversion is used to control the amount of cane fed to the knives.

Extraction.—The sucrose of sugar cane is a component of the plant juice or sap held within the myriad cells of the cane. In order to extract it, the strong fiber structure must be crushed. Simple pressure will break the pith cells and liberate the cell contents. Greater pressure is required to obtain juice from the rind.

Since sugar cane is a strong plant, a large amount of power must be used in the extraction of the juice. The plant must be prepared before it can be fed to the mill. This preparation consists of even feeding of the cane by the use of cane levelers, cutting the plant with the aid of revolving knives, and crushing it by passing the plant through a three-roller unit. In some factories, one two-roller unit or a number of such units and a shredder are used. Because of this preliminary treatment the mill rollers can grip the plant more easily. The entire process results in tearing the cane and breaking open the cells which hold the sap. The more completely the cells are ruptured, the more complete the juice extraction. Crushing makes the pith juice more easily available. As much as possible should be liberated in the crushing step in order to obtain the greatest amount of juice. During this process, about 60% of the juice is extracted.

The prepared cane is fed to the mills, which generally consist of a series of three-roller units. The cane passes between the first bottom roller and the top roller and then between the top roller and the second bottom roller, so that a double squeeze is obtained with each unit. The surfaces of the mill rollers are grooved in order to increase the gripping power of the surface and to facilitate drainage of the juice. During

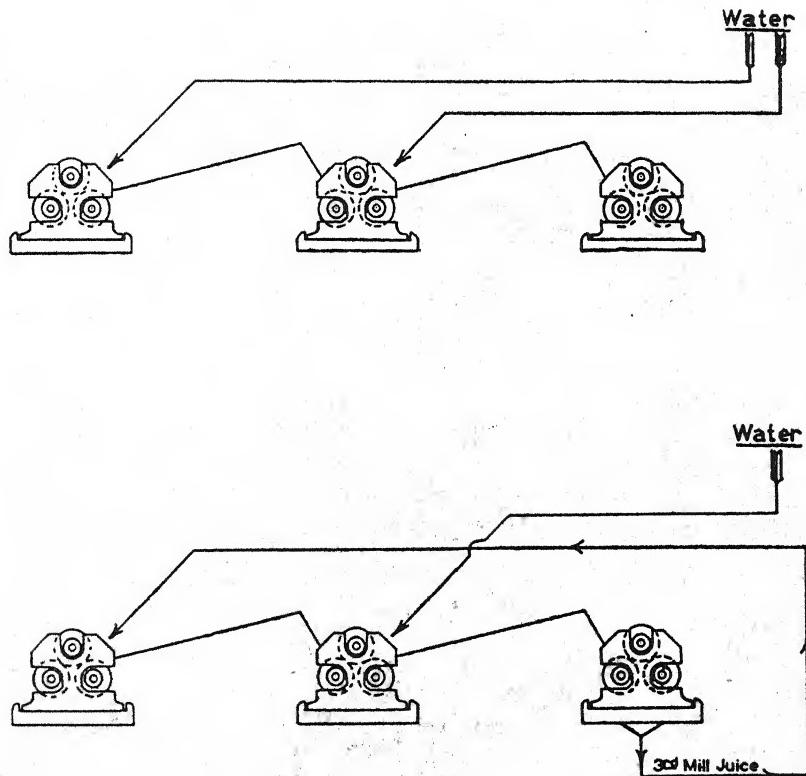


Fig. 128.—Maceration process; upper mills represent the process of simple maceration; lower mills represent the process of compound maceration.

the milling, the cane is sprayed with water to wash the sap away from the fiber. The cane is carried from unit to unit under increasing pressure by means of an intermediate carrier, during which time the bagasse, or residual fiber, is sprinkled with either dilute juice or water, so that a maceration effect is obtained. If the diluent used in a three-mill extraction is water, the process is known as simple maceration. If the juice from the third mill is added to the bagasse from the first mill, the process is known as compound maceration. See Fig. 128. Davies¹ describes a number of crushers,

¹ J. G. Davies, *Principles of Cane Sugar Manufacture*. Rodger, London, 1938.

shredders, and mills. The comparative chemical composition of juices of different varieties of Louisiana sugar cane is discussed by Fort and McKaig.²

The juice obtained is a very dark, opaque liquid containing 12 to 16% sucrose and small amounts of dextrose, levulose (resulting from the inversion of some of the sucrose), pectin, gums, lipids, organic acids, protein, and other nitrogenous materials. It has an acid reaction and holds some fiber, wax, clay, dirt, and gases in suspension.

The bagasse is baled and used for fuel. In the United States, it is being used for the manufacture of fiberboard. In 1943, the use of bagasse for the manufacture of wrapping paper was still in the experimental stage.

Clarification.—The juice obtained by milling is passed through a stationary copper or brass metal screen or through rotating or revolving screens to remove gross suspended material such as pieces of bagasse. In order to remove dissolved or colloidally suspended material, the juice is treated with lime or other chemicals such as sulfur dioxide and heat. Calcium hydroxide suspension (milk of lime) is added to bring the pH of the juice to 8.0–8.4. Lime is to be preferred to soda for raising the pH value because it also forms insoluble calcium compounds with some of the impurities present in the juice. The elevation of the pH is necessary because sugar-cane juice is acid; consequently, if this acidity is not neutralized, some of the sucrose will be hydrolyzed and a loss in recoverable sucrose will occur. The addition of lime also aids in the coagulation of some impurities which rise as a scum to the top of the vessel. The rising of impurities after the addition of calcium hydroxide suspension is effected by the entrainment of air dissolved in the juice. The neutralized juice is heated to 212–215° F. and then permitted to stand so that the precipitate of calcium phosphate, coagulated protein, and other impurities such as gums, pectins, and lipids can settle.

The process of clarification is varied in several ways. If the phosphate content of the original juice is low, sufficient lime is used to raise the pH to 9.5–10.0, and phosphoric acid is then added to reduce the pH to 7.6 in order to precipitate the calcium as calcium phosphate. Then the mixture is heated and settled. *Hot liming* consists of heating the juice first to 212–215° F. and then adding hydrated lime. The process can take place in two stages. The pH of raw cane juice ranges from 4.8 to 5.6. In the first stage, the pH is increased to 6.3 with lime. This mixture is heated. More lime is added to obtain a pH of 7.6 and, at times, the mixture is reheated. Thus, advantage is taken of coagulating some of the colloids on the acid side. *Compound clarification* consists of clarifying the juice from the crusher and the first mill (the primary juice) and then adding the settling to the juice from the second mill, which undergoes a separate clarification treatment. The clarified juice from the second mill is added to the juice from the crusher and first mill, and actually goes through a second clarification process.

If, during clarification, excess lime is removed by the addition of carbon dioxide, the process is termed carbonatation or carbonation. If sulfur dioxide is used in the defecation process, the step is known as sulfitation.

² C. A. Fort and N. McKaig, Jr., U. S. Dept. Agr., *Tech. Bull.* 688 (1939).

Sedimentation.—Sedimentation is carried out in settling tanks, generally cylindrical in shape with a conical bottom, or rectangular with a sloping bottom. These vessels are usually filled through the bottom. There are two principal methods of subsidence, the batch or intermittent method and the continuous method. Generally cylindrical vessels are used for the latter method while rectangular vessels are used for the former.

In the batch type of sedimentation, the juice is allowed to settle for one to two hours and the clarified liquor is then decanted through a series of valves at different levels or through a float device connected to one valve, while the slops and sludge are discharged through a plug at the lowest point of the bottom of the tank. The scum may be run off into tanks to be treated with more lime and then filtered.

In the continuous type of clarifier, the sap is settled in a series of superimposed shallow trays, or in vessels in which the direction of flow is suddenly changed so that the particles of the precipitate are arrested by impingement. In either type, the clarified juice from the settling tanks goes to the evaporators, while the slops, sludge, and mud are filtered.

Filtration.—The mud is discharged into a mud blowup tank containing an open steam coil so that steam mixes with the mud. Hydrated lime is added in such proportion that the resultant clarified liquor will have a ρH as near to the ρH of the decanted clear juice as possible. This practice prevents the formation of a precipitate in the mixed juice and also prevents fouling of the evaporators. The sludge is boiled. The mixture is filtered by pressure in a filter press with the use of filter aids to prevent flattening out and to retain cake porosity. The basic function of a filter aid is to provide a porous cake structure.³

The technological aspects of filtration and clarification⁴ have been discussed by a number of investigators.

Evaporation.—Multiple-effect evaporators of the four- or five-stage type are commonly employed in the production of raw sugar. Technical considerations limit the number of vessels in an evaporator unit to five or six. In a multiple-effect evaporator, the juice in a second vessel is heated and evaporated by the heat derived from the condensation of the vapor obtained by heating the juice in the first vessel by steam. This is shown diagrammatically in Fig. 129. The arrangement produces the greatest economy and efficiency. In the first section of the evaporator, a slight vacuum and a high temperature are employed. In the second section, the temperature is reduced and the vacuum is increased. In the third section, the temperature is reduced still more and the vacuum is still further increased. It is important to conduct the boiling in such a way that there is little loss because of entrainment, that is, the carry-over of fine drops of sirup into the condenser is kept to a minimum.

The juice is fed into the first section of the unit, usually by pump but occasionally by gravity. It is transferred from section to section by the differences in pressure which exist in the different vessels. This flow takes place through pipes and may be

³ A. B. Cummins, *Ind. Eng. Chem.*, **34**, 403 (1942).

⁴ *Ind. Eng. Chem.*, **34**, 403-429 (1942).

controlled by valves. The sirup of higher density which collects in the third, fourth, or final section is drawn off by a pump. Depending upon the efficiency of the unit and other factors, the sirup produced contains about 45-55% sucrose, its specific gravity ranging from about 1.20 to about 1.26.

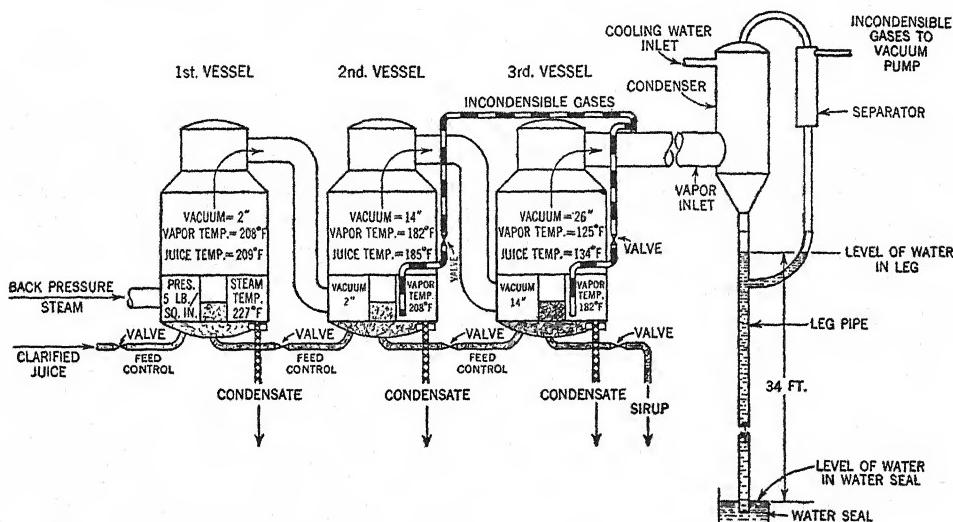


Fig. 129.—Triple-effect evaporator.

Crystallization.—The yellow or yellowish-brown, thick, viscous liquid obtained in the multiple-effect evaporator is stored in tanks and drawn off as needed for the vacuum pan. In the vacuum pan, generally a single-effect unit in which operations can be controlled rigidly, the evaporation is continued until the sirup has a specific gravity of about 1.5, equivalent to about 90% solids. This sirup is supersaturated with respect to its sucrose content, that is, crystals of sucrose will deposit if the conditions are proper. The degree of supersaturation is termed the supersaturation coefficient. Expressed mathematically, it is the ratio of the sucrose present in the supersaturated sirup to that present in a saturated sirup. Generally a saturated cane sirup contains less sucrose per unit of water than a saturated solution of sucrose in water.

As the evaporation of the first charge of sirup proceeds to the point at which it can be drawn into threads (stringproof), an additional charge of cold sirup is added to induce crystal formation. Once crystals appear, it is necessary to operate the vacuum pan in such a way that no new crystals appear and that none which have formed are dissolved. The appearance of new crystals is termed secondary granulation. Sirup is fed continuously or intermittently until the pan is full and the crystals have grown in size. As additional charges of sirup are added, the supersaturation is lowered and crystal formation stops. By reducing the vacuum and increasing the temperature, false granulation can be corrected. The "massecuite" which is formed is emptied

(struck) into a crystallizer by turning off the steam, breaking the vacuum in the pan, and opening the discharge valve. Masscuite is a mixture of sucrose crystals and mother liquor or molasses. Other terms often used for this mixture are "melada" or "magma."

Crystal formation may be induced by several procedures. In the seeding method, a small amount of finely ground white sugar is introduced into the boiling mixture. In the waiting method, crystallization takes place because of the continued removal of water. In the shock method, crystallization takes place spontaneously when the supersaturation coefficient reaches a given value, following an increase in the vacuum and a subsequent lowering of the boiling temperature.

Separation.—The charge from the vacuum pan is dumped into a mixer, in which the mass is slowly stirred to increase the crystal yield and to prevent lumping. It is subsequently transferred to a centrifugal device which consists essentially of a perforated metal basket or drum lined with two metal screens attached to a spindle which can be rotated at high speed. Under the influence of centrifugal force, the molasses (A or first molasses) moves through the screens and the perforated metal drum, away from the center, while the crystals (A sugar) remain in the basket. Because the A molasses obtained from a first crystallization still contains crystallizable sucrose, it is returned to the vacuum pan with additional syrup from the multiple-effect evaporators. The B masscuite produced from this mixture is centrifuged and, again, the resultant (B or second) molasses is returned with additional syrup to the vacuum pan. This treatment yields raw sugar of A and B quality. The C molasses produced is returned to the vacuum pan only when the process has not exhausted the possible yield of sucrose. The C sugar produced is sometimes bagged and sold, but generally is mixed with syrup to form a magma which is used with A and B masscuites to form A and B quality raw sugar. The sucrose-exhausted molasses is called blackstrap, and is used in the fermentation industries. The A and B raw sugars are bagged or even shipped in bulk to refineries.

Considerable progress in sugar technology has made possible the production of sucrose of such high purity directly from sugar-cane and sugar-beet juice, without further refining. Such sugars are called "direct consumption sugars."

(b) Refined Sugar

The steps previously described were used in the production of raw sugar, also known as 96° test sugar. Considerable further processing is necessary to produce refined cane sugar. See Fig. 130. As previously mentioned, the raw sugar is shipped in bags or in bulk from the factories located near sugar plantations to the refineries located in the United States, Canada, and Europe.

After weighing and sampling for assay for payment of duty and for settlement between seller and buyer, the jute bags which contain the raw sugar are dumped into crushers which break up large lumps. The crushed crude material is stored in raw sugar bins. The bags are washed with hot water and recovered for re-use, while the sugar solution formed is concentrated and used for the recovery of the sugar.

Washing or Affination.—The raw sugars pass from the sugar bin, sometimes by bucket elevator, to a mingler, where the thin layer of adhering molasses is removed by mixing with sirup containing about 70–72% sucrose. A paste or magma is formed. This mixture is passed into a centrifuge analogous to the type used in the manufacture of raw sugar where the magma is sprayed with water under pressure. The sirup obtained from the centrifugals, known as affination sirup, is mixed with additional sirup. Only as much of the raw-sugar magma-affination sirup is passed back to the mingler to form more magma as is necessary to give a transportable sirup mixture.

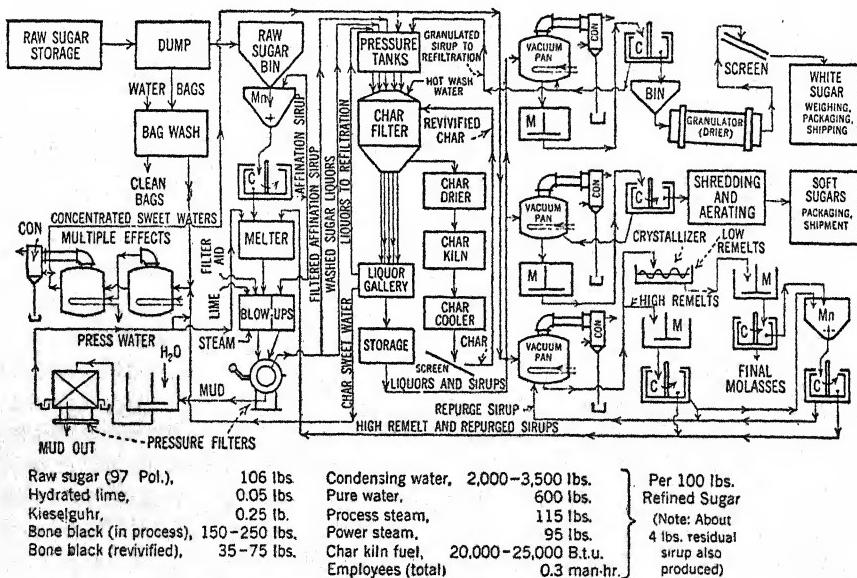


Fig. 130.—Refined cane sugar flowsheet. (Courtesy Food Industries.)

The excess affination sirup is usually treated separately, and occasionally is evaporated and processed into raw sugar.

Dissolving or Melting.—The washed raw sugar, now a light yellow, is dissolved in the melter with water and heat obtained from exhaust steam. Mechanical stirrers are used. The amount of water employed is about 50% of the weight of sugar being dissolved.

Defecation or Clarification.—Since the washing process removes only surface impurities, impurities in the crystals themselves must be removed by a method analogous to the clarification treatment described on page 540. The sirup from the melter, after transfer to blowups (tanks equipped with steam coils and compressed air outlets), is treated with sufficient calcium hydroxide suspension to raise the pH to 7.3–7.6 in order to neutralize the acids carried over in the raw sugar. The temperature is increased to 180° F. or higher with steam, while the material is agitated by the air

supply. The resulting precipitate carries down much of the suspended matter consisting of pectins and albumin which may be present. When pressure filters are not used, phosphoric acid must be employed as previously described (page 540). A filter aid is added to the hot mixture which is run through a pressure filter yielding a brilliant amber-colored liquid. In Europe, carbonatation is more commonly employed than are filter aids.

Incomplete defecation yields a juice containing excessive quantities of coloring matters, nonsugar organic materials, and lime salts. Large amounts of the latter lead to evaporator scaling and poor juice boiling qualities.

Decolorization.—The filtrate from the previous treatment is clear of suspended solids but defecation does not remove much color. This is performed principally by adsorption on bone black. While the primary purpose of the use of animal charcoal is the removal of color, it also aids in the removal of other organic and inorganic impurities. About 0.3 to 1 pound of char is used for each pound of dissolved sugar. If the decolorization process is to be continuous, then some of the bone black has to be reclaimed and reactivated by drying in a char drier, heating in a kiln at 1000–1200° F., cooling to 160° and returning to the sugar solution. Such a process generally requires full-time operation with high capacities. In more recent years, certain raw-sugar plants have begun to refine sugar with the aid of activated carbons of the Suchar Norit, and analogous types which require the use of relatively small amounts of decolorizing agent.

The char filters are metal cylinders about 8–10 feet in diameter and about 24–30 feet high, with conical tops and bottoms. They are provided with a manhole on top and two manholes near the perforated bottom for the removal of the bone black. The sirup–bone black mixture, heated to 160° F., is filtered through blanket or felt material under pressure.

Boiling or Crystallization.—The clear, colorless filtrate may be stored or transferred to the vacuum pan. As explained above, the control of temperature and vacuum is important and needs constant attention. To obtain large crystals, only a small amount of the liquor to be processed is placed in the pan and only a small number of crystals are obtained. As more sirup is added and if the conditions are kept right, the crystals already in the mixture grow larger with little, if any, formation of new crystals. To obtain a large number of small crystals, a large volume of sirup is placed in the vacuum pan at the beginning of the treatment. Hard sugars are generally processed so that the temperature in the vacuum pan is maintained at 160–180° F., while soft sugars are produced by holding the temperature down to 120–130°.

Separation.—The mixture from the vacuum pan is passed into a mixer, in which paddles keep the cooling sugar mix from forming a solid mass and then into a centrifuge similar in design to those described for the manufacture of raw sugar and to those used during the affination process. These centrifuges separate the refined crystals from the sirup, which is often washed away with water or steam. The washed crystals pass into a drier known as a granulator. It is an inclined cylinder, about 5–6 feet in diameter and about 25 feet long, which contains saw-tooth shelves. The sugar is

lifted by the shelves as the drum revolves so that the sucrose can fall down through a blast of heated air. There are usually two or three drums in tandem. The sugar is cooled while falling through the second and third drums, which are not heated.

Granulated sugars are treated as described above, but soft sugars pass from the vacuum pan to the mixer, to the centrifuge, and thence to a shredder and aerator.

The concentrated sweet waters obtained from the bag washing, and the repurge sirups, may be processed in another vacuum pan, while the sirups from the finishing centrifuges either are returned to the vacuum pans directly or are reintroduced in the melter or in the decolorization step.

Grading and Packing.—The white sugar obtained from the granulator is passed through sieves or screens so that various sizes can be separated. These are packed either for bulk or retail sale in barrels, 100-pound bags, etc., or for retail sale in cartons, small cotton bags, or paper bags. Some granulated sugar is pressed while warm and moist into blocks which are cut into cubes or parallelepipeds (loaf sugar), the latter form generally being individually wrapped for restaurant use. The cubes or loaves may be prepared by pressing in moulds a mixture of refined sugar and simple syrup which is subsequently dried. Powdered sugar is manufactured by grinding the sucrose crystals and adding sufficient cornstarch to retard lumping.

2. Beet Sugar

Beet sugar provides about 35% of the total amount of sucrose produced. The sugar beet does not produce a yield of sucrose per acre equivalent to that of the sugar cane; but because it can be grown in climates in which the sugar cane will not grow it has been intensively cultivated in Germany, Russia, the United States, and France.

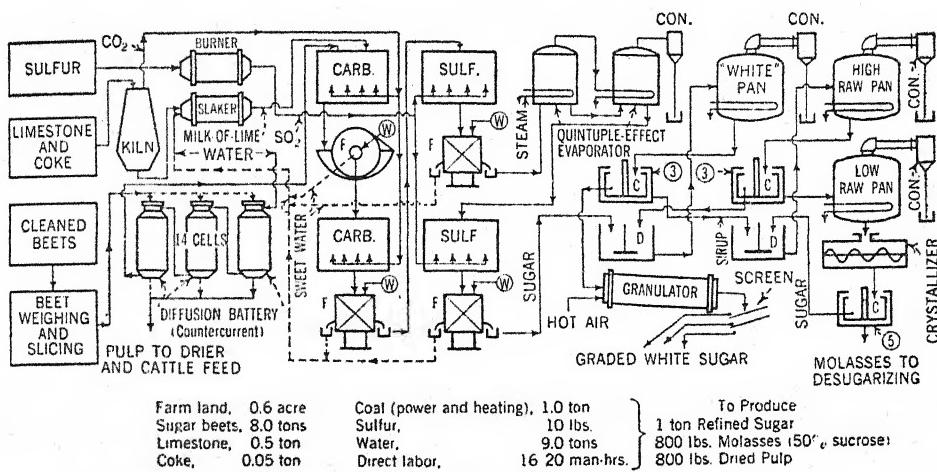
(a) Extraction

Because of the essential difference in the type of plant, for the sugar beet contains more water and less fiber than the sugar cane, the sucrose contained in the sugar beet must be extracted by a process entirely different from that used for the extraction of sugar from the sugar cane. Basically, the process consists of dialyzing the sugar beets in a diffusion battery run on the countercurrent system.

The beets, after removal from the ground, are shorn of their tops and crowns in the field. They are loaded on trucks drawn by tractor, mule, or horse, and carted to plants near-by, or else are loaded into railroad cars to be transported to factories more distantly located. When they reach the refining plant, the beets are dumped into canals or sluiceways, and are moved forward by shafts in these canals against a stream of water so that they rub each other clean by friction. Sometimes other methods are used to wash the beets.

The clean beets are floated into the plant where they are cut by machines into thin slices or ribbons. The washed and weighed slices are run into vertical diffusion cells. These are upright cylinders connected by piping, the outlet on the top of one cylinder being connected to the inlet on the bottom of the next diffuser. About 14 cells com-

prise a diffusion battery. Each cell is filled with beet slices (the beet cells acting as dialyzing membranes). The pipes are arranged in such a manner that tap water meets those slices which are almost sugar exhausted, while freshly cut beets meet the most concentrated extract in the diffusers. This is the countercurrent method of exhaustion. The warm extraction fluid takes about 20 minutes to pass through each diffusion cell, and may be reheated between the cells to the required temperature, which is about 185° F. A high temperature favors rapid dialysis, but too high temperatures break down the cell membranes of the beets and permit more impurities to



KEY: CARB., CARBONATORS; SULF., SULFITORS; F. FILTERS. W. WASH WATER. C. CENTRIFUGALS, CON., CONDENSERS; D. DISSOLVERS

Fig. 131.—Beet sugar flowsheet. (Courtesy Food Industries.)

enter the extraction fluid. When the sugar content of the diffusion extract is high enough to warrant handling, that is, when it reaches about 15%, the extract is piped into a clarifier. The pulp remaining after extraction is dried and used for cattle feed.

The liquor obtained by the diffusion process is screened through finely perforated metal sieves. It is almost black in color and must be clarified. This is done with lime which neutralizes the acid, carbon dioxide which aids in precipitating excess calcium, and heat which assists in coagulating the proteins. The process, as mentioned previously, is termed carbonation. Some plants use water, others use the sweet water filter washings, for slaking the lime. The juice may be filtered, given another carbonation treatment, re-filtered, and then treated with sulfur dioxide in order to reduce the depth of color and to prevent decomposition. Sometimes three carbonation treatments are needed. The liquor from the sulfite processing is filtered and passed into multiple-effect evaporators. The raw sugar is obtained by evaporation in vacuum pans.

Methods for the purification of sugar-beet juices by continuous carbonation and

clarification have been developed. Some of the factors controlling these methods are discussed by Skaar and McGinnis.^{4a}

(b) Refining

The remainder of the processing is very similar to that used in refining cane sugar. Figures 130 and 131 show the essential differences in these operations.

Modifications of the beet-sugar process have been proposed in which dehydrated beets⁵ are extracted in diffusers. These yield a diffuser juice containing about 50% sucrose.

3. Sorghum Sugar

Sorghum, which is closely related to the sugar cane, looks like Indian corn. Sweet varieties of sorghum can yield sucrose in quantities per ton comparable to those derived from domestic sugar cane. Sorghum molasses may be exhausted by extraction methods used in commercial raw cane-sugar practice.

The failure to effect a practically complete removal of starch from sorghum juice is one of the principal causes for the lack of success in the commercial production of sucrose from this plant. The increase in viscosity caused by the presence of gelatinized starch reduces circulation during the evaporation step and thus limits the crystallization of the sucrose. It is not feasible to convert the starch by use of diastase because of the cost of the enzyme, the resultant increase in nonsucrose sugars, and the increase in operating difficulties. However, by use of a centrifuge⁶ with a horizontally baffled basket and with a nonperforated wall, it is possible to separate 85% of the starch from the juice. By subsequent defecation of the centrifuged juice with lime, about 95% and in some cases 98-99% of the starch is eliminated. Thus, with further processing by methods analogous to those previously described for cane sugar and beet sugar, sorghum sugar can be obtained.

4. Malt Sugar

The term generally identifies a mixture of maltose and dextrin in varying proportions produced by the action of a diastatic enzyme on gelatinized starch. It is not to be considered synonymous with maltose.

The following process for the manufacture of malt sugar (Fig. 132) has been developed after a critical study of the various factors which affect the quality of malt sugar.⁷ It is based on the gelatinization of starch under steam pressure; conversion by barley malt at a high temperature, followed by filtration; neutralization, followed by a second filtration; concentration to 25% solids with subsequent percolation through bone char and a third filtration; concentration in a vacuum pan; and drying on a rotary drum drier. Corn flour, wheat flour, or starch may be used as the raw material, but the principal one is corn flour.

^{4a} K. S. Skaar and R. A. McGinnis, *Ind. Eng. Chem.*, **36**, 574 (1944).

⁵ B. J. Owen, *Food Industries*, **1**, 699 (1929).

⁶ E. K. Ventre, H. S. Paine, and S. Byall, *Am. Chem. Soc. Abstracts*, 105th meeting, April, 1943.

⁷ W. O. Gordon, *Food Industries*, **15**, No. 6, 60 (1943).

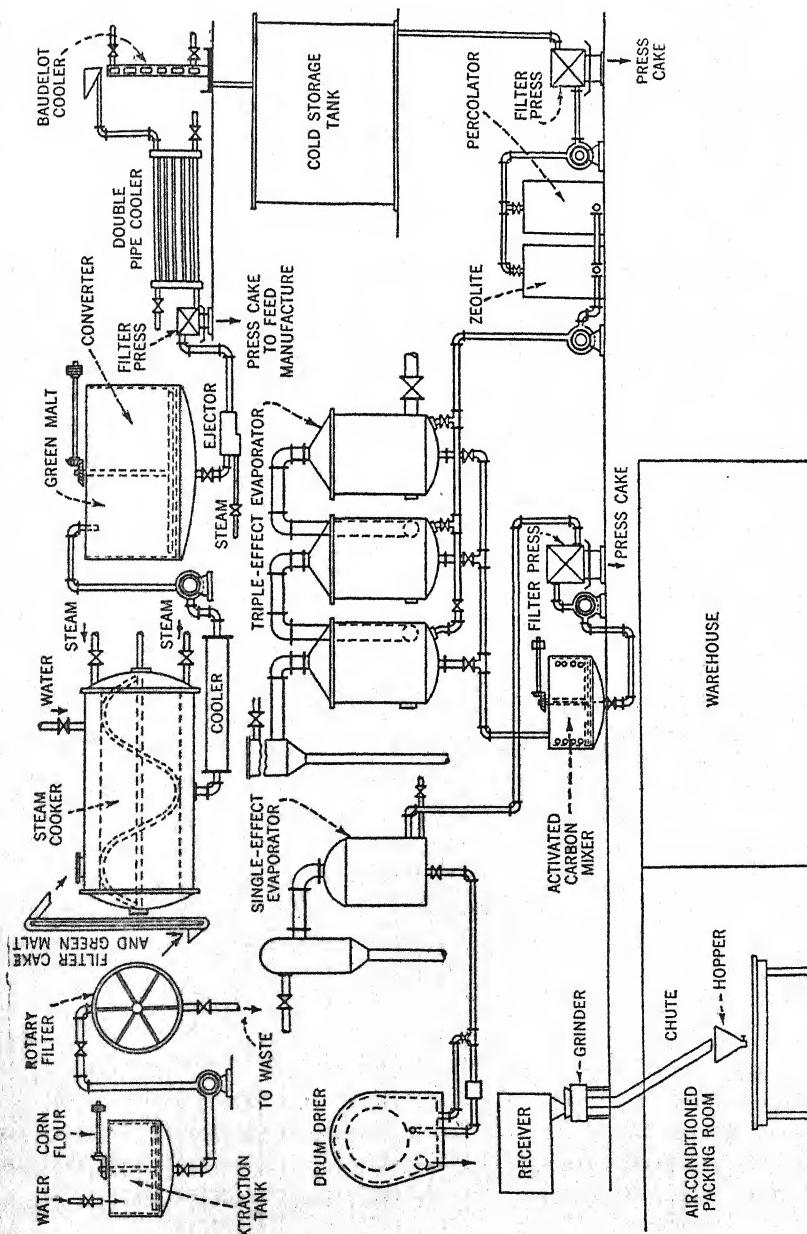


Fig. 132.—Malt sugar flowsheet. (From W. O. Gordon, *Food Industries*, 15, No. 6, 61 (1943).)

Ground barley malt, in the proportion of 150 pounds of malt to 2000 gallons of water, is added to water in a horizontal cooker equipped with a series of steam-jet inlets and agitators. The malt is stirred in the water at 120° F. for one hour; 4000 pounds of corn flour is added; and the mixture is brought to 156°. As the temperature reaches this point, the mass becomes thick but is liquefied within a few minutes by the malt. The reaction mixture is cooked at 10 pounds' pressure with steam for 10-30 minutes. The pressure is increased to 25 pounds so that the mixture can be blown into a glass-lined converter equipped with agitators. The sudden reduction in pressure during the transfer results in the explosion of the partially gelatinized starch particles. After cooling, the mixture in the converter is treated with 200-300 pounds of ground green malt, which is sprouted but unkilned barley. The amount added depends upon the diastatic activity of the malt. At 158°, approximately equal amounts of maltose and dextrin are produced in from $\frac{1}{2}$ to 1 hour. After the action of the diastase has continued sufficiently, the mash is heated to above 160° to inhibit further action of the enzyme. At 185°, the filtration is started. Plate and frame filters are preferred by Gordon.⁷ The liquor from the filter press is neutralized with hydrated lime or sodium hydroxide using phenolphthalein as the indicator, but the pH must be carefully controlled not to exceed a value of 8 in order to avoid darkening the solution. The liquor is then filtered again. After partial concentration to 25% total solids, the mixture is percolated under pressure through bone char to remove color, and is passed through a zeolite filter to remove calcium salts which may cause coagulation of milk protein if the malt sugar is to be used in infant foods. The decolorized solution is concentrated in a triple-effect evaporator, heated with 1-2% of activated carbon, filtered and passed to a single-effect evaporator in which it is concentrated to 55-60% total solids. The sirup produced is pumped or sucked to a drier of the rotary vacuum drum type. It is best to have as high a vacuum as possible during the drying step. The drier is a bronze cylinder, about 5 feet in diameter, 12 feet long, and heated internally with low-pressure steam, and revolves in an enclosed housing under steam. The sirup is sprayed on the revolving drum and a thin film is dried as the drum revolves. The dried material is scraped off with a knife and passes from a receiver to a grinding machine and thence to the hoppers of packing machines.

This process can be greatly improved by the use of refrigeration. The liquor from the second filtration and from the bright portions of the first filtration may be pumped through a double-pipe counterflow cooler and then over a direct-expansion ammonia cooler which reduces the temperature of the mixture to approximately 35° F. The solution may then be blended with other batches in glass-lined tanks at this low temperature for 48 hours. During this period, most of the starch and some of the undesirable proteins are precipitated and may be removed by filtration.

5. Dextrose

In the manufacture of sugar from corn, cornstarch diluted to form a milk of 18-22% Bé. is treated in converters with heat, acid, and pressure in a manner analogous to that

described for corn sirup (page 558). The acidified starch milk is heated at about 40-45 pounds' pressure until all the starch is converted. The time of conversion is longer than that required for corn sirup because the starch is not only changed to dextrin and maltose but is also almost entirely converted to dextrose. The liquor obtained from the converter is transferred to neutralizers, in which the pH of the mixture is raised to 4.8-5.2 with sodium carbonate. It is filtered, decolorized with activated carbon, evaporated in multiple-effect evaporators, decolorized again with activated carbon, evaporated again in a single-effect unit, and allowed to crystallize. Too much alkali may not be added, for the sirup will become colored again during the char filtration.

(a) *Crude Dextrose Sugar*

A number of types of dextrose products are prepared. In the preparation of the crude sugar, the mixture is poured into tanks and, after partial crystallization, is cut into slabs which are aged to permit as complete crystallization as possible. This product contains about 70-80% dextrose, while the remainder consists of dextrin and water. These sugars are commonly called "70" or "80" sugar depending upon the approximate percentage of dextrose. The dextrins present give crude dextrose sugar a light brown color.

(b) *Pressed Dextrose Sugar*

Pressed dextrose sugar is obtained by squeezing the sirup coming from the vacuum pan in hydraulic presses. This operation separates most of the sugar from the dark colored mother liquor, called corn molasses or hydrol.⁸

(c) *Cerelose*

The sirup from the vacuum pan is permitted to stand at about 90° F. after being grained with pure dextrose. After crystallization has taken place, the mother liquor is removed by centrifugal methods previously described. Cerelose contains about 9% water, the remainder being practically all dextrose.

(d) *Anhydrous Dextrose*

Cerelose is dissolved in water in the melters until a sirup with a specific gravity equivalent to about 28-30° Bé. is formed. This mixture is decolorized with activated carbon by heating to 160° F. for about 30 minutes. The liquor is then passed through a filter press and refiltered before storage. As needed, sirup is withdrawn from the storage tank to a single-effect evaporator in which it is concentrated until it begins to grain. A large volume of 30° Bé. sirup is added, and the mixture is evaporated until a high supersaturation coefficient is obtained.

⁸ Corn Industries Research Foundation, *Corn in Industry*, 1941.

Refined dextrose sugar is made by refining processes similar to those used in the cane sugar industry.⁹ The sirup from the vacuum pans is passed into warm cylindrical tanks in which it is stirred by a spiral agitator so that solid lumps of crystals and dextrose hydrate cannot form. Crystallization takes place in from six to ten days. The mixture of crystals and sirup is then centrifuged, passed to a tandem of cylindrical rotating drum driers, and sifted. A product consisting of 99.5-99.8% dextrose is produced.

The manufacture of *hydrate dextrose* has been described by Newkirk.¹⁰

6. Levulose

Levulose can be recovered from artichokes.¹¹ The artichokes are washed, sliced, and dehydrated soon after harvesting in order to prevent a decrease in sugar content while awaiting extraction. The extraction is performed in a manner like that described for beet sugar. The extract of inulin which is produced is acidified with sulfuric acid until the *pH* is 1.5, and is then heated for one hour at 176° F. to hydrolyze the polysaccharide. After hydrolysis, powdered calcium hydroxide is added to raise the *pH* to 7.5. The precipitate of calcium sulfate and coagulated proteins is removed by filtration, and the filtrate is treated with lime at about 60° F. in order to precipitate calcium levulate. This is performed by a continuous process so that the precipitate may be washed quickly and carried to the carbonation step without loss of too much levulose. The suspension of the calcium salt of levulose is filtered, washed, resuspended in water, and carbonated at 60° F. The solution of levulose obtained by this treatment is freed from calcium carbonate by filtration. It is concentrated in a vacuum pan at 140° to about a 40% sirup. It is generally refiltered and evaporated again in a vacuum pan to form a 90% sirup. As the temperature is gradually decreased, crystallization takes place. The mixture is then centrifuged as previously described to separate the levulose crystals from the mother liquor.

Other methods of levulose manufacture have been described.¹² Levulose has also been produced by using chicory and dahlia tubers as the source of inulin.¹³

7. Lactose

Milk sugar can be recovered from whey powder by the following process.¹⁴ The whey powder is wet thoroughly with 95% alcohol. This light paste is added to more alcohol, agitated, and filtered as rapidly as possible. The residue is a protein concentrate. The filtrate, containing the lactose in supersaturated solution, is treated with hydrochloric acid. Lactose crystals are introduced to start crystallization.

⁹ W. B. Newkirk, *Ind. Eng. Chem.*, 28, 760 (1936).

¹⁰ W. B. Newkirk, *Ind. Eng. Chem.*, 31, 18 (1939).

¹¹ J. W. Eichinger, J. H. McGlumphy, J. H. Buchanan, and R. M. Hixon, *Ind. Eng. Chem.*, 24, 41 (1932).

¹² M. J. Proffitt, *Ind. Eng. Chem.*, 27, 1266 (1935).

¹³ P. V. Golovin, N. A. Bryukhanova and A. T. Fridman, *J. Sugar Ind. USSR*, 3, 140 (1929).

¹⁴ *Ind. Eng. Chem., News Ed.*, 17, 373 (1939).

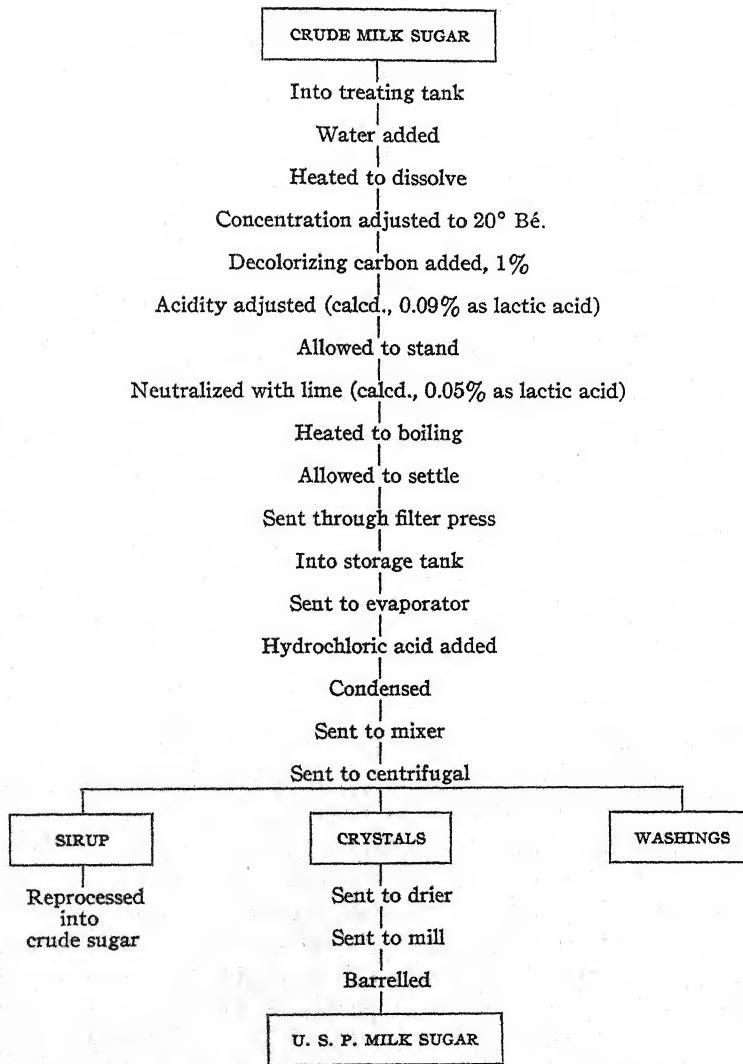


Fig. 133.—Refiner milk sugar operations.¹⁶

When crystallization is almost complete, the lactose is filtered out and washed in alcohol. The remainder is distilled to recover the alcohol, while the residue is a vitamin concentrate containing riboflavin.

An alternative method, based on extraction with 70.7% alcohol and subsequent acidification with 1.0 % by volume of a 1.7 N hydrochloric acid solution in absolute alcohol, is described by Leviton and Leighton.¹⁵

¹⁵ A. Leviton and A. Leighton, *Ind. Eng. Chem.*, 30, 1305 (1938).

¹⁶ W. E. Stringer, *Food Industries*, 11, 262 (1939).

A flowsheet for the manufacture of crude milk sugar is given by Stringer.^{16a} Whey, obtained as a by-product in the manufacture of cheese, is placed in a coagulating tank. The acidity is reduced from about 0.4 to 0.05% (calculated as lactic acid) with hydrated lime. The mixture is heated to boiling, by steam escaping from a perforated steam coil, to coagulate the albumin and aid in the precipitation of the calcium compounds. The decanted liquor and the filtered sludge are transferred by a pump to a double-effect evaporator where the lactose mixture is concentrated to about 20° Bé., that is, about 30% lactose. This sirup is reclarified, filtered, and passed to a single-effect evaporator where the lactose liquor is concentrated to grain. This occurs at about 40–45° Bé. When it has grained sufficiently, a strike is made, and the contents of the vacuum pan are dropped into a mixer. The batch of sugar crystals is kept turning just fast enough to keep the mother liquor and crystals in motion. This mixture is then passed by gravity to centrifugals in which the crystals are recovered and washed as previously described. The crude lactose crystals are spread by hand on screen trays and placed in a tunnel drier. The first washings from the centrifugals are generally used for the recovery of more lactose by reconcentration in a single-effect evaporator and repeating the above process.

U. S. P. grade lactose is obtained by the series of steps outlined in Fig. 133.

II. SIRUPS

The United States has been particularly fortunate in the number and disposition of sirups that are available for consumption. Since the honeybee is no respecter of sections of the country or of State lines, honey is produced in almost every part of the country.^{17, 18} In the deep South, sirup from sugar cane is predominant. Toward the Southwest, and somewhat north of the deep South, sorgo sirup obtained from the sorghum plant takes its place. The corn belt yields cornstarch from which corn sirup is made. Maple sirup is recognized as the predominant sirup of New England as a whole and of Vermont in particular. The boundaries of taste and fancy, on the other hand, show no limits, so that these products are to be found distributed throughout the country. But precisely because of this there are a large number of sirups from which the consumer may make his choice, and even this comparatively large choice is expanded by the trade names which are used to describe these products.

1. Sirups from Sugar Cane

A number of different sirups are obtained from sugar cane. These are top or cane sirup, molasses, refiners' sirup, and sugar sirup.

(a) *Top Sirup*

Top sirup is cane sirup obtained simply by boiling the whole juice of sugar cane.

^{16a} W. E. Stringer, *Food Industries*, 11, 72 (1939).

¹⁷ *Consumers' Guide*, 3, No. 24, 7 (1937); 3, 25, 14 (1937).

¹⁸ E. Oertel, U. S. Dept. Agr., *Circ.* 554 (1939).

It has a flavor similar to that of molasses but, in a high-quality sirup, there is a delicacy and fineness of flavor molasses lacks, particularly since the more recent methods of exhausting molasses have been made available. Cane sirup must not contain more than 30% of water nor more than 25% of ash.

The juice is obtained by grinding in a three-roller mill. It is run off into settling tanks from which it can be drawn off into evaporating pans, but it is generally filtered through cloth before being placed in the evaporators. These are long, shallow, copper or galvanized iron pans, 15 feet long, 6 feet wide, and 5 or 6 inches deep, set on an incline so that the front section at which the juice enters is lower than the end section at which the sirup leaves. The juice is kept about $2\frac{1}{2}$ inches deep at the entrance and the sirup level is about 1 inch deep. The thin layer promotes rapidity of evaporation. In addition, the pans are equipped with baffles which impede the flow of the juice, thus making the path of the flow longer. Many of the pans are heated by direct fire as was formerly the case when kettles were used, although there has been an increase in the use of steam-heated devices. The latter are preferred because there is seldom any overheating or burning. Steam coils also produce a more even heating and a greater speed of evaporation. The scum rising to the top is skimmed off by hand in about the first third of the pan. In continuous processing, the juice is admitted at such a rate that it is finished sirup when it reaches the drawoff end. The juice is generally boiled until the temperature reaches 223–224° F. This corresponds to a Brix reading of 71–72° at 70–72° F., equivalent to about 69–70% sugar because the sirup also contains the nonsugar solids of the original juice.

Packing the sirup in cans is usually carried out at 160° F. or at a slightly higher temperature. The cans are often cooked at 185° for 10 minutes to prevent spoilage. With varieties of cane which yield sufficient quantities of invert sugar, the possibility of crystallization in the sirup is avoided.

In operations of still greater magnitude than those described above, the cane is ground, crushed, and milled to provide larger quantities of juice. Since this results in a juice which contains more impurities, it must be subjected to greater processing than juice containing less impurities. Generally, the juice is screened and passed over baffles while being treated with sulfur dioxide obtained by burning sulfur or from cylinders of the gas. The sulfur dioxide increases the acidity of the juice. Care must be taken to see that this acidity does not exceed 35 ml. of 0.1 N sodium hydroxide solution per 100 ml. of sample using phenolphthalein as the indicator. As in the treatment of cane and beet sugar, milk of lime is added to the juice after the sulfitation, but the amount must be kept sufficiently low so that it will still require 15 ml. of 0.1 N sodium hydroxide solution per 100 ml. of sample.

Treatment with sulfur dioxide serves to decolorize the juice. After the reduction of the acidity, the juice is mixed and heated to the boiling point, causing coagulation of the proteins and precipitation of some of the impurities. Those rising to the top are skimmed off. Mixing, heating, and skimming may be repeated two or three times. The heated juice is permitted to stand for an hour or so for sedimentation to take place and is then drawn off, leaving the sludge in the tank. The clarified juice

is concentrated in open-pan, automatically controlled, steam-heated evaporators similar to those described above in which relatively thin layers of the juice are processed or vacuum pans may be used.

In order to produce a uniform product it is often necessary to regulate the acidity, the sugar content, and the color of the sirup. If the latter is too deep, the sirup is treated with activated carbons which reduce it. However, these carbons also remove some of the flavor, an undesirable factor in this type of processing.

To prevent crystallization of the sirup after packing, small quantities of invertase are added to convert some of the sucrose to invert sugar. The invertase is added to the partially concentrated juice at a temperature of 140° F. Then the evaporation is continued until the specific gravity is 1.30, which is equivalent to about 62-63% sugar.

(b) Molasses

Molasses is a by-product of the manufacture of raw white or brown sugar from sugar cane. A proposed definition of this product is: the product which remains after separating sugar from the clarified and concentrated juice of the sugar cane. It may be light or dark. It contains not more than 25% of water and not less than 55% of total sugars.

The liquid product remaining after the removal of crystals is termed the mother liquor. In this sense, molasses is a type of mother liquor, since it has been separated from crystallized sucrose. It is generally concentrated and clarified but still contains the color, flavor, and minerals of the original massecuite, melada, mush, or concrete from which the crystallized sugar was obtained. It also contains some of the lime and sulfur dioxide and possibly other materials used in the manufacture of sucrose. These chemicals leave their mark on the molasses flavor. Furthermore, because of the more complete methods of exhausting molasses, there is much less sucrose in commercial molasses than in old-fashioned molasses.

The methods for the manufacture of this product have been described as a part of the production of raw sugar. See pages 538 *et seq.*

Commercial and trade practice brands molasses sold for human consumption under two main groups known as "first molasses" and "second molasses." As far as consumers are concerned, these terms are synonymous with "light molasses" and "dark molasses," respectively. The Food and Drug Administration defines light molasses as molasses which contains not less than 62% of total sugars. Dark molasses is molasses which contains not less than 55% of total sugars. In all cases, the molasses must contain not more than 25% of water.

There are many other types of molasses having their own peculiar flavor and name. Two of the better known are Barbados and blackstrap molasses. The former has a distinctive rumlike flavor. The latter is the lowest grade of molasses from which all the possible crystallizable sugar has been removed. It is used mainly in stock feed and for the production of alcohol and sometimes vinegar.

(c) Refiners' Sirup

Refiners' sirup is the residual liquid product obtained in the process of refining raw cane sugars. It contains not more than 25% of water and not more than 8% of ash. It varies from dark brown to almost colorless, with a cane sirup taste which is, however, not so strong as that of molasses. There are many variations in grade and quality of refiners' sirup as in the variations of sugar-cane sirups, which run from the lowest or blackstrap grade to that of top cane sirup. The lowest grades of refiners' sirup are not supposed to be used for human consumption. The methods for the manufacture of this product have been described as part of the description of the refining of raw cane and beet sugar.

(d) Sugar Sirup

Sugar sirup is the product made by boiling down sugar and water to a sirupy consistency. It must not contain more than 35% of water in order to conform to the standards of the Federal Government. This type of product may not be labeled cane sirup even if the sirup is made with sucrose manufactured from the juice of the sugar cane. The only exception to this labeling is the mixed sirup commonly called "cane and maple" sirup to which the consuming public has become accustomed.

2. Beet-Sugar Sirup

A sirup can also be made from sugar-beet juice. It has not found much favor in this country because of its peculiar flavor, but it is used in Germany.

3. Sorgo Sirup

Sorgo is a sirup made from the juice of the sorghum plant which, as previously mentioned, is related to the sugar cane. This sirup resembles cane sirup in flavor but has a sharper tang. Federal requirements postulate that it must not contain more than 30% water nor more than 6.25% ash on a dry basis.

Sorgo sirup is still made by old methods. In small-scale manufacture, the sorghum is topped, the leaves are removed, and the cane is crushed in an iron roller or in a mill. A ton of sorghum yields sufficient sap, depending on the amount of crushing, to give 10-30 gallons of sirup. The juice is sieved through straw filters to remove the bagasse and coarse dirt. In some cases, clay is added and heat is used to coagulate and sediment the dirt. Sorgo sap contains starch, as noted on page 548, and is sometimes treated with diastase or malt extract to hydrolyze the starch. The clarified juice is run into shallow, baffled, evaporating pans and heated to boiling, and the scum is skimmed off by hand as it forms. The boiling is continued until the sirup is concentrated to 70-80° Brix, after which it is cooled rapidly, and transferred to cans, jars, and jugs.

In larger plant operations, the process is even more like that of the manufacture of top sirup from cane-sugar juice. The sorghum cane is crushed in better mills, clar-

fied by use of filter aids and frame filter presses, decolorized with activated carbon, and evaporated in vacuum pans.

4. Corn Sirup

Corn sirup or commercial glucose is the product made from cornstarch by incomplete hydrolysis. In a more general way, the products known commercially as glucose, mixing glucose, and confectioner's glucose are thick, sirupy, colorless products made by incompletely hydrolyzing starch or a starch-containing substance, and decolorizing and evaporating the product to a proper consistency. The production of this material is not limited to the use of cornstarch; but since by far the greater portion of this type of sirup is made from corn, it is customary to use that name. Commercial glucose is not a product of definite composition. It is a mixture of dextrins, including the higher dextrins such as erythrodextrin, and the sugars, dextrose and maltose. A great deal of commercial glucose sold is not water-white, but is colored by the addition of other sirups and materials such as refiners' sirup, sorgo sirup, and molasses.

The entire terminology and nomenclature given to this and allied products are confusing. There is a definite substance which is known as dextrose or D^+ -glucose, if proper chemical nomenclature is used (see Volume I, page 64). Because of the latter chemical name, this substance is often confused with the indefinite material called "glucose" which has been described in the previous paragraph.

In the manufacture of corn sirup, starch recovered from corn kernels, as described on page 469, is suspended in water and passed from measuring tanks into converters built to withstand a pressure of 50 pounds per square inch. The starch suspension is acidified with hydrochloric or sulfuric acid and heated until the starch is hydrolyzed, as evidenced by failure of a sample to give a starch-iodine reaction. The mixture is partially neutralized in vats with sodium carbonate by raising the ρH to about 5.0. Before filtration in filter presses, it is centrifuged to be freed of the gross precipitate. The filtered, dilute sirup is partially decolorized with activated carbon before being passed into triple-effect evaporators for concentration. After treatment with activated carbon again, the partially concentrated sirup is concentrated to a greater extent in a vacuum pan. It is cooled, transferred to drums or tank cars or is stored. It may also be mixed with the sirups previously mentioned.

5. Maple Sirup

Maple sirup is the product prepared by the evaporation of maple sap or by the formation of a solution of maple sugar. In order to conform to Federal Government specifications, it must not contain more than 35% water, and the finished product must weigh at least 11 pounds to the gallon. It is produced mainly in the northeastern part of the United States, Vermont and New York being the principal producing States. However, since the hurricane of 1938 ruined many good maple trees, the yield may be reduced for some time to come.

The trees are tapped for the sap in the early spring by boring holes about 2-4 feet

from the ground, about $1\frac{1}{4}$ to $\frac{3}{8}$ inch in diameter and about $2\frac{1}{2}$ to 3 inches through the bark into the wood. The boring slopes slightly upward. Plugs are inserted to permit the sap to run into collecting vessels such as galvanized iron pails or wooden buckets of 12-16 quarts capacity. The collecting vessels are usually equipped with covers. The spouts should fit tightly into the boring and should have lugs from which the pails may be suspended.

The sap is generally collected each day, and is strained through cheesecloth or a metal strainer before being placed in storage, if it cannot be processed immediately. If the sap is held longer than 24 hours it must be refrigerated to avoid fermentation. The liquid is poured into slightly tilted flat pans corrugated in such a manner that the flow of the sap is impeded. The sap should not cover the corrugations to a depth greater than one inch. Fires under the pans, generally wood fires because this is the fuel most easily available, cause the layer of sap to evaporate rapidly. The scum is removed by hand. Foaming during evaporation is generally controlled by the addition of some material such as cream, milk, or egg white. The boiling is continued until a temperature of $217-218^{\circ}$ F. is reached. This is equivalent to about 65% sugar. The finish boiling point is about 7° above the boiling point of water at the production point elevation. The Baumé hydrometer reading is 30.5° at the boiling point and 35.5° at normal temperature. This is equivalent to a specific gravity of 1.32. Since maple sap contains from 1.5-4% sucrose, with the median content from 2-3% sucrose, the sap must be concentrated to $\frac{1}{25}-\frac{1}{30}$ of its original volume. After concentration, the hot sirup is filtered through felt. It is preferable to allow it to sediment before filtration. Lead contamination may be removed by cold or hot filtering and by the addition of 1% dried milk powder before filtration.¹⁹ In larger operations, filter presses are used. In small establishments, the sirup is canned or placed in jars while still hot. In larger manufacturing operations, it is transferred to standardizing tanks where its composition is adjusted before bottling.

If the sirup is further concentrated until it crystallizes as a brown sugar, maple sugar is obtained. A good tree will yield about two pounds of maple sugar or a quart of sirup per year.

6. Artichoke Sirup

Palatable sirups can be made from artichokes.²⁰ After washing, slicing, drying, and diffusing, as previously described (see page 552), until a liquor containing 35% total solids is obtained, the extract is filtered and treated with sufficient hydrochloric acid to decrease the pH value to 4.2. This mixture is digested at 25 pounds' pressure for 20 minutes to hydrolyze the inulin. The hydrolyzate is concentrated in a vacuum pan to about 60% total solids. The pH of the liquor obtained is raised to 5.4 with sodium carbonate, after which it is filtered; its color is reduced to a light or golden

¹⁹ C. J. Tressler and W. I. Zimmerman, *Food Industries*, 13, No. 10, 52 (1941).

²⁰ F. A. Dykins, E. C. Kleiderer, U. Heubaum, V. R. Hardy, and D. T. Englis, *Ind. Eng. Chem.*, 25, 937 (1933).

brown with activated carbon and it is then concentrated to about 82% total solids in a vacuum evaporator.

This method has been modified by Englis and Fiess²¹ by the use of organic exchangers. The general procedure for the preparation of the extract is the same as that briefly outlined above. After heating the extract to 140° F., it is treated with Zeo-Karb H and is mixed gently. Sufficient Zeo-Karb H is added to reduce the pH to 3.4. The liquor is decanted from the exchanger and hydrolyzed at 15 pounds pressure per square inch for 30 minutes. The hydrolyzate is decolorized with Darco and treated with Amberlite IR-4, after which the pH is raised to 6.7. The mixture is again decanted from the precipitate, filtered, and finally concentrated under reduced pressure at a temperature not over 122° until the solids reach 80%.

7. Honey

Honey is the nectar and sweet exudations of plants gathered, modified, and stored in the combs by honeybees. In order to be pure honey within the meaning of the definition of the Food and Drug Administration, the product must be levorotatory. Other requirements for honey are that it must contain not more than 25% water, not more than 0.25% ash or mineral matter, and not more than 8% of sucrose. The latter requirement is due to the fact that honeybees will normally convert sucrose into its hydrolytic products, dextrose and levulose. When the bees obtain all of their nutrient from flowers, this conversion occurs almost completely. If, however, the bees are fed on sucrose to a large extent, they apparently tire of the effort in the conversion and leave some of the sucrose unchanged during the modification process.

Honey is sold in a number of forms, such as extracted honey, comb honey, strained honey, chunk honey, shallow-frame comb honey, whip honey, wrapped cut-comb honey, etc. Extracted honey is honey which has been separated from the uncrushed comb by centrifugal force or by gravity. Strained honey is honey removed from the crushed comb by straining or by other means of filtration or sieving. Chunk honey consists of pieces of comb with extracted honey poured over them. Whip honey is the light, cream-textured product made by whipping granulated honey. The other terms are self-explanatory. The honey sold in small sections called comb honey is usually the better grade. The grades, color standards, and packing requirements for honey are described in a circular of the United States Department of Agriculture.²²

In small-scale production, the bee is permitted to build its honeycomb itself; but in larger-scale production, the beekeeper buys wax foundations which fit into the wooden frames of artificial beehives. This practice regulates the weight of the frames and permits the bees to spend more time gathering nectar because it is no longer necessary for them to build the comb. When the frames have been filled, the bees usually cap the comb with their own wax.

In order to extract the honey, the beekeeper slices off the caps with a warm knife.

²¹ D. T. English and H. A. Fiess, *Ind. Eng. Chem.*, 34, 864 (1942).

²² U. S. Dept. Agr., *Circ.* 24 (1933).

The open comb is placed in a centrifuge in which it is rapidly whirled. Under the action of centrifugal force, the honey moves away from the comb in a manner similar to the separation of the molasses from sucrose crystals.

To be able to manage bees to the best advantage, a beekeeper should have available data as to the honey flows, or the succession of bloom, of the important honey plants in his locality.²³ With this information, he can calculate the usual time for the installation of package bees, division of colonies, swarm control, removal of honey, requeening, and preparation for wintering. This information is discussed by Oertel. The location of the beehives, the type and amount of nectar secretion, and the amount of pollen available are important factors.

TABLE 37
MAJOR PLANT SOURCES OF HONEY

Plant	Rank as honey source	State
Alfalfa.....	First.....	Idaho, Nevada, Oregon, Utah
	Second.....	California, Colorado, Kansas, Montana, Nebraska, Oklahoma, South Dakota, Wyoming
Alsike clover.....	First.....	Indiana, Maine, Maryland, Massachusetts, New York, Ohio, Pennsylvania
Sweet clover.....	First.....	Alabama, Colorado, Connecticut, Illinois, Iowa, Kansas, Michigan, Minnesota, Montana, Nebraska, North Dakota, Oklahoma, South Dakota, Wyoming
	Second.....	Idaho, Indiana, Nevada, New Jersey, Oregon, Utah, Wisconsin
White clover.....	First.....	Arkansas, Connecticut, Indiana, Louisiana, Missouri, New Jersey, Tennessee, Vermont, Virginia, West Virginia, Wisconsin
	Second.....	Illinois, Iowa, Maryland, Massachusetts, Michigan, Minnesota, New York, Ohio, Pennsylvania, Washington

Not only is nectar secreted by the nectaries of flowers, but also by certain plants such as vetches, cotton, partridge-pea, and a few others which produce it from special areas called extrafloral nectaries on the leaves or stems. Honeydew is an exudation produced on the surface of leaves and trees by insects such as plant lice or aphids, scale insects, gall insects, and leafhoppers. It differs from floral nectars in that it contains a large amount of dextrins which make it highly dextrorotatory. At times, the flow of honeydew is of considerable importance and provides a source of food when floral nectar is unavailable.

The honey which is used commercially is actually the honey made by the bees in excess of the requirements of the colony. The amount required by a colony is of the order of 400 pounds per year. The surplus produced in an average season is about 50 pounds.

²³ E. Oertel, U. S. Dept. Agr., *Circ.* 554 (1939).

The most widely distributed principal honey plants are alfalfa, alsike clover, sweet clover, and white clover. The States which rate them as first or second in importance as honey producers are given in Table 37.

There is a great difference in the color of honeys. California white-sage honey ranks as the finest of the white honeys, with honey from orange blossoms and white and alsike clover next in preference. The lightest honey, however, comes from fireweed and is water-white in color and mild in flavor. Large amounts of light honey which are, however, of a poorer flavor, are also obtained from alfalfa and sweet clover. The strongest flavor and the darkest color are obtained with honey from cultivated buckwheat. Other dark honeys are obtained from fall flowers such as the goldenrod and the aster.

Granulation in honey is the result of the crystallization of hydrate dextrose. If very coarse grains are formed, the honey is not considered of a high grade. Granulated honey ferments more easily. This has been explained by Dyce²⁴ to be the result of the increase of water and decrease of sugar in the liquid phase.

²⁴ E. J. Dyce, Cornell Agr. Expt. Sta., *Bull.* 528 (1931).

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Chapter XVIII

CONFECTIONERY AND CACAO PRODUCTS

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Candy is a delicacy because it offers a certain flavor and appearance that appeals to our normal appetites. It is the job of the confectionery manufacturer to properly gage the public's taste in order to offer a product that will be suitable.

The greatest advance made in the past quarter-century in the art of candy and chocolate manufacture has been in the adoption of methods for standardized mass production. This advance has been made possible by the work of scientists and other experienced men who have made a careful study of production methods and the chemical reactions behind these methods. The question is often asked as to how confectionery was made in the earlier days without our present detailed knowledge. The answer, of course, is that time has the ability of mellowing our impressions of a former period. Handmade candy depended upon the experience of an operator who had learned the art by methods of trial and error. Mass production is only possible after a thorough study of the process is made and the reasons for reactions are carefully worked out.

I. MANUFACTURE OF CHOCOLATE

An important industry that lends itself to mass production is the chocolate and cocoa industry. Chocolate is made from the cacao bean, the seed of *Theobroma cacao*, grown in most countries situated in the tropical belt. The principal producing countries in 1939 were: Africa (the Gold Coast, Nigeria, the Ivory Coast, and Cameroun), Brazil (Bahia), with smaller crops from Ecuador, Venezuela, San Domingo, and others. The total exportation of beans for 1939 was over 1 $\frac{1}{2}$ billion pounds.

In size, shape, and appearance the cacao resembles a shelled almond.¹ Twenty-five to 75 of the seeds are found in one pod (the fruit of the tree). When ripe, the pods are carefully removed from the tree. In order to prepare the beans for the market and remove adhering pulp, they are fermented and dried. The dried beans are shipped to the manufacturer for processing. As the beans reach the factory, they consist of the shell (approximately 14%) and the inside of the bean, called the nib (approximately 86%).

¹ See Volume I, page 828, for a more detailed description of the cacao bean, its cultivation, fermentation, and curing.

In the cocoa trade and chocolate industry, cacao beans are designated according to either the port of export or the country or state of origin. Of the average yearly crop of about 712,000 long tons, the distribution among the various types is approximately as given in Table 38.

TABLE 38
DISTRIBUTION OF VARIOUS TYPES OF CACAO^a

Trade designation	Source	Per cent of total crop, 1939
Accra.....	West coast of Africa	45.7
Lagos.....	Nigeria	19.5
Bahia.....	North Brazil	18
Guayaquil		
Machala		
Arriba.....	Ecuador	1.8
Trinidad.....	British West Indies	1.0
Caracas }		
Puerto Cabello }	Venezuela	1.4
Maracaibo }		
Sanchez.....	Santo Domingo	3.9
Others (including Ceylon, San Thome, Java, Haiti, Panama, Para, Grenada, Costa Rico) }		8.7

^a Based on export values for 1939 (see page 826, Volume I).

1. Roasting

After a thorough mechanical cleaning the beans are roasted. In order to produce a good quality chocolate it is important that every step in its manufacture, from the picking of the ripe fruit to the packing and storage of the finished product, be carefully performed. However, of all the manipulations involved in the manufacture of chocolate and other cacao products, the roasting of beans is, perhaps, one of the most important.

Before the cacao is ready for the production of its various products, it must be stripped of its shell and also have the characteristic chocolate aroma developed in it. These steps are made possible by roasting. The roasting dries out the shell and makes it friable, so that it can easily be removed from the nibs or kernel of the bean. There are two different theories given as to the development of aroma in the cacao during roasting. The aroma may be the result of the reaction between various components of the beans, or it may be a residual flavor noticed only after the removal of certain disagreeable and more volatile substances. In support of the latter theory, Gephart,² reporting on the work of Bainbridge and Davies in the factory of Cadbury in England, mentions the steam distillation of 2000 kilos of low-roasted Caracas with a yield of 24 grams of a volatile oil. This oil had a true chocolate flavor and high chocolate flavoring properties. By fractional distillation of the oil, they found a substantial amount of the compound *d*-linalool, and noted that the distillates possessed an odor

² F. C. Gephart, *Food Industries*, 1, 62 (1929).

resembling coriander. Defrens³ found that there is no noticeable development of aroma until a considerable amount of the water present in the bean is removed.

There are many types of roasters on the market, usually classified as to the type of fuel employed, *i. e.*, gas, coal, oil, or wood, and as to whether the roaster is heated directly by the burning fuel or by preheated air. In the hands of an experienced and careful operator, any type will give good results. It is difficult to lay down hard and fast rules to be followed in making a roast because there are many factors to be considered. The reaction to heat of even the same variety of bean will not always be the same, depending upon the natural moisture content and size of the bean. However, with careful control of time and temperature for a given type and weight of beans, it is possible with proper judgment and experience to obtain a fairly uniform roast.

The more common type of roaster consists of a rotating cylindrical drum which is heated directly by coal, gas, or oil under a forced air draft supplied by a pump fitted on the machine. As the cylinder turns, the beans are heated and some of their moisture driven off as steam. The steam and other volatile materials pass out at the sides of the roaster. Although widely used, it has the disadvantage that, should the beans be brittle and inclined to break, portions of the shell are charred, and there is a risk of giving the beans a smoky flavor. The charge of a roast may vary from 100 to 300 pounds; and the length of the roast will depend upon the type of bean and the weight to be processed. The greater the amount of beans, the longer is the roasting period. A temperature of 95–110° C. is considered sufficient for a low roast, while 110–120° C. is the normal roasting temperature. Usually, for chocolate products, a low roast is preferred, but for cocoa a higher roast is needed to help in the subsequent fat removal. As soon as the roasting is judged to be completed, the hot beans are discharged into cooling trucks where they are quickly cooled by blowing cold air over them. If they are not cooled rapidly, over-roasting effects may result. The beans should be cracked and dehusked as soon as cooled in order to maintain the aroma at its peak. Aroma is found to be conserved by melangeuring with sugar soon after roasting.

In the larger factories where continuous processes are needed, the roasting procedure has undergone drastic changes. In one of the most modern methods employed, raw beans are fed into the bottom of a rotating kiln rising at an angle of about 10° for some 30 feet. A concurrent preheated air blast is also charged into the kilnlike structure. As the beans are roasted they are moved up to the end of the kiln by means of protruding ribs or baffles on the inside of shaft. The temperature of the kiln as well as the speed of the beans can be accurately controlled. Once the beans reach the top they are hurled with great momentum against a metal disk. The force of the contact breaks the bean and liberates the nib from the shell. The lighter shell is blown up and out of the system with the waste gases and air, while the nibs drop into a hopper. The nibs are "cured" in the hopper by the residual heat that they still possess. The curing is a continuation of the roasting. The nibs and included germ, or embryo (about 0.5%), are ready for milling. In this method, the husking and winnowing processes are not needed.

³ G. Defrens, *Food Industries*, 2, 248 (1930).

In any roasting method the main results are:

1. Development of the characteristic chocolate aroma.
2. Evaporation of excess moisture.
3. Heat changes in the tannins and bitter astringent substances present, resulting in a more palatable product.
4. Volatilization of unpleasant volatile compounds like acetic acid and acetic acid esters.
5. Drying out of the shell so that it becomes brittle and can be easily removed from the nib.
6. Killing of any cacao moth ova and larva that may be present.

TABLE 39
TYPICAL MOISTURE CHANGES DURING ROASTING^a

Analysis	Nib, %	Shell, %	Whole bean, %
Raw bean	87.5	12.5	100.0
Moisture	6.6	1.6	8.2
Water-free material	80.9	10.9	91.8
Moisture lost during roasting	4.6	1.4	6.0
Moisture left after roasting	2.0	0.2	2.2
Moisture, nibs = 100 per cent	2.4	..	...

^a Adapted from H. W. Bywaters, *Modern Methods of Cocoa and Chocolate Manufacture*. Blakiston, Philadelphia, 1930.

Although a low roast may be improved during subsequent operations, it is difficult to correct a high roast in regard to aroma.

2. Husking and Winnowing

As far back as 1664⁴ it was a native custom to dehusk the bean and use only the kernel, or nib, for making chocolate. The quality of the finished cacao products depends upon the completeness of the shell removal. The shell is composed of fibrous material difficult to digest, has no food value, and cannot be easily ground to a fine mass. Furthermore, the shell does not add to the desired chocolate aroma of the bean and may impart a definite off-odor.

The shell separation takes place in the cracker and fanner. As the whole beans come from the roaster they are dry and brittle, the shells being lighter and less dense than the nibs. These physical characteristics are the basis for the method. The whole beans are cracked between rollers adjusted to the size of the beans. The cracked beans are passed over a series of rotating cylindrical sieves. Similar sized fragments of nib and shell come in contact with a countercurrent air blast that will blow the lighter shell away. In modern practice, shaker "decks" are fitted to the winnowing machine. These decks aid in the final cleaning of the nibs by removing pieces of shell that may be overlaid by the heavier nib. Although the allowable shell content of the nibs is about 2%, efficient winnowing can produce nibs with not much more than 1% of shell. The shell content will depend upon the production rate of the machine.

⁴ A. W. Knapp, *J. Soc. Chem. Ind.*, 37 (July, 1918).

According to Knapp,⁵ 100 pounds of raw beans will produce, after the winnowing operation, the products outlined in Table 40.

TABLE 40
DIVISION OF WHOLE BEAN AFTER ROASTING AND WINNOWING^a

	Pounds
Loss on roasting.....	7.0
Usable nibs (2% shell).....	78.5
Shell.....	10.5
Fines (germs and shellis).....	4.0
	<hr/>
	100.0

^a Based on 100 pounds of raw beans.

The nibs are used in the manufacture of cocoa, chocolate, and cacao butter. The by-products are also utilized. Table 41 gives the typical composition of roasted nibs and

TABLE 41
COMPOSITION OF ROASTED NIBS AND ROASTED SHELLS^a

Analysis	Nibs, %	Shells, %
Moisture	2.72	4.87
Fat	50.12	2.77
Theobromine	1.04	0.49
Caffeine	0.04	0.16
Other nitrogen substances	12.12	14.54
Pure starch (by diastase)	8.07	4.14
Crude fiber	2.64	16.63
Other carbohydrates	19.57	46.40
Total ash	3.32	10.48
Water-soluble ash	1.16	3.67
Water-insoluble ash	2.16	6.81
Acid-insoluble ash	0.02	2.51

^a M. A. Pozen and R. Schwartz, *Mfg. Confectioner*, 8, 33 (Nov., 1922).

shells. Cacao shells have long been recognized as an established article of commerce. Large quantities of the ground shells, known as cocoa-shell meal, are consumed in the manufacture of commercial mixed fertilizers. A certain amount is used in the preparation of proprietary feed mixtures, particularly of the calf meal type. The shells are also used for the extraction of theobromine. In some cases, they may be used as a fuel, having an average calorific value equal to two-thirds that of bituminous coal.⁶ Assuming that the raw bean will yield 10% shell, 65,000,000 pounds of shell were available in 1941 in the United States for these uses.

The fines, which consist of the germ (embryo) and shell, are utilized as a fuel and as a source of a cheaper grade of cacao butter.

⁵ A. W. Knapp, *J. Soc. Chem. Ind.*, 37, 240T (1918).

⁶ For an excellent discussion on the commercial utilization of cacao by-products see G. P. Walton and R. F. Gardiner, U. S. Dept. Agr., *Bull.* 1413 (1926).

3. Nib Blending

The proper blending of cacao nibs is important to the manufacturer of cacao products for many reasons. He must maintain a product standardized as to color, flavor, appearance, and eating qualities; this requires that variations in individual lots of beans must be surmounted by judicious selection among the varieties of beans. Economy and competition force the manufacturer to devise a blend of different cacaos that will not only compare favorably as regards cost and flavor with competitive products, but that will also be unique and difficult to imitate. The product that is to be finally manufactured must also be considered. A milk chocolate will require a different blend from a sweet or vanilla chocolate, while a coating for nutmeats will not be similar in blend to a cream center coating.

The art of blending consists of an empirical balancing of aroma and sweetness against strength, astringency, and bitterness. The process is empirical because the final decision depends upon the individual idiosyncrasies of the tasters. Generally, blending consists of adding a small amount of the finely flavored cacaos to a basic and cheaper priced cacao. Jensen⁷ grades the roasted cacaos^{7a} as follows:

1. Java, Ceylon, Samoa, New Hebrides, etc.
2. Puerto Cabello, Maracaibo.
3. Arriba.
4. Caracas, Carupano, Trinidad, Grenada.
5. Bahia, San Thome, Cameroon, Accra, Lagos.

The blending operation takes place after the roasting of the beans because of the lack of uniformity among the different types. The actual method of blending is ordinarily carried out by mixing together the required weights of the different varieties.

4. Milling

Chocolate liquor, also called bitter or baking chocolate, is produced by the grinding action of cacao mills on the nibs. In the consumer's opinion, smoothness is the most important single factor for a good quality of chocolate. The steps in making chocolate after the winnowing process are primarily concerned with reducing the particles comprising the cacao mass to as small a size as possible. The first actual disintegration of cacao solids takes place in the mills and, although the fineness of grind is not important to the final quality of the chocolate, does help subsequent refining if it is thorough. However, fine grinding is necessary if cocoa powder is to be made from the liquor, since it is the only grinding it will receive. Poor grinding is reflected in a poor cacao butter yield and a cocoa powder of poor suspension power.

According to Whymper,⁸ milling has these advantages:

⁷ H. R. Jensen, *Chemistry, Flavouring and Manufacturing of Chocolate Confectionery and Cocoa*. Blakiston, Philadelphia, and J. and A. Churchill, London, 1931.

^{7a} For a description of the more important of these cacaos see Volume I, page 834.

⁸ R. Whymper, *Cocoa and Chocolate*. Blakiston, Philadelphia, 1921.

1. Preliminary reduction of the nibs to a moderately fine condition.
2. Thorough blending of the mixed and blended nibs.
3. Convenience of storage of liquor blocks as compared with storing bags of nibs.
4. Rupturing of the fat cells and reduction of nibs to a homogeneous mass so as to allow easy expression of the cacao butter in the press.

The milling takes place between horizontally turning stones (see Fig. 134, page 573). French buhrstones are preferred, and the grinding surfaces are cut into grooves, or "dressed," for maximum effect. The stones are arranged in pairs, of which the top stone revolves, and a series of 2 or 3 pairs are arranged to give a consecutive grind. The nibs are delivered by gravity chute to the hollow center of the top stone. During the grinding, a temperature of 40° C. or over develops, and, because of the high fat content (over 50%), the ground mass becomes fluid and flows down the series of stones.

The chocolate liquor produced by the mills has the composition given in Table 42.

TABLE 42
COMPOSITION OF CHOCOLATE LIQUOR

	Per cent
Moisture.....	1.70
Fat.....	54.00
Theobromine.....	1.08
Caffeine.....	0.42
Other nitrogen substances.....	0.42
Pure starch (by diastase).....	8.21
Crude fiber.....	2.65
Other carbohydrates.....	17.32
Total ash.....	3.04
Water-soluble ash.....	0.72
Water-insoluble ash.....	2.32
Acid-insoluble ash.....	0.02

The liquor may be used in one of the following three ways:

1. It is moulded and sold as chocolate liquor to confectioners and bakers.
2. It is sent to the pressroom to be converted into cacao butter and press cake.
3. It is sent to the chocolate department to be worked up into different varieties of chocolate.

5. Melangeuring

Chocolate liquor that is to be changed into the many chocolate products possible is obtained from the liquor mills and then combined with the needed ingredients. The possible formulas of the different chocolates—plain, sweet, semisweet, milk, buttermilk, etc.—are too numerous to consider. However, chocolate may be considered basically as an intimate mixture of sugar, cacao nibs, and other ingredients. Small quantities of flavoring materials such as vanillin, coumarin, coffee, cinnamon, peppermint, orange, lemon, anise, and synthetic cacao-bean flavor may also be used. In order to prepare the ingredients for the final grinding, they are first mixed in a

chaser mill or melangeur. These machines are roller mills. Two large granite rollers are suspended on an overcarriage, and ride on a rotating steel or granite bed that is heated by a steam coil. Scrapers are fitted to guide the material continually under the rolls. The amount of grinding taking place here is very slight; in many cases, this step can be omitted with little effect on the final quality of the chocolate. However, it does help in completing a better blending of the various ingredients and prepares the mass for the final grinding process. The product from the melangeurs, because of the thickening effect of the added sugar, has the consistency of a heavy paste.

6. Refining

To obtain the desired smoothness in a chocolate, the particles present must be disintegrated to colloidal or near-colloidal size. This is essential; no matter how delicate the blend may be, if the particles are coarse, the full flavor will not be apparent. Normally, a smooth tasting effect may be obtained by using a high cacao butter content. The present tendency is to save cacao butter by the addition of certain stabilizers such as lecithin. In these instances finer grinding is imperative in order to obtain the sensation of smoothness. This fine grinding of the chocolate is done in the refiners, or finishers.

A refiner usually consists of five steel rollers revolving at different speeds. The bottom roller may have a speed of 20 r. p. m. and the top one a speed of 100 r. p. m. These rollers are perfectly machined, water-cooled cylinders, and exert an even pressure throughout their entire length. The chocolate paste is fed in between the bottom pair of rollers. The thin film of chocolate which forms is carried up the series by the increasing speeds of the individual roller. Careful adjustment is necessary, since the fineness of the chocolate depends entirely upon the spacing of the rollers and their speed. Because of the action of the cylinders, the chocolate particles are subjected to both a grinding and a tearing effect. At the top, the chocolate is detached by a scraper and falls as a flaky powder into a truck, to be finally sent to the tempering room. Because of the grinding and the chilling, the chocolate loses its fluidity and becomes powdery. Modern refiners will reduce chocolate from a fineness of about 0.004 inch (the fineness of powdered sugar) to a fineness of about 0.0006 to 0.0008 inch in one or two treatments.⁹

7. Conching

The chocolate obtained from the finishers is now sufficiently fine to be moulded. However, in preparing a high-quality product, the chocolate should first be conched. Conching, or kneading, will yield a product with greatly increased flavor, smoothness, and viscosity stability.

The ordinary conche (originally it was shell-like in form, hence its name) consists essentially of a large tank with a concave bed of granite or steel. The ends of this

⁹ B. J. Zenlea, *Mfg. Confectioner*, 27 (May, 1941).

"pot" are curved. The whole tank can be heated by steam or hot water. The tank contains a roller to which a continual to-and-fro motion is imparted by means of a crank propelled by a geared wheel. As a result of this motion, the chocolate is subjected to a rolling pressure. In addition, a beating action is obtained when the chocolate mass in front of the roller hits the curved end plates and is thrown to the back of the roller, the material making a figure-8 movement. The full effect of this beating action depends upon the quantity of chocolate in the conche and on the size of the machine. Best results are obtained when the conche is not too full or too large. A typical conching period ranges from 96 to 120 hours. Figure 135, page 573, shows a 4-tank conche.

The general effects of conching are:

1. To blend the ingredients and produce their full flavor.
2. To drive off moisture and a considerable quantity of volatile acids with a corresponding decrease in the residual harshness and acridity left in the chocolate by the raw cacao.
3. To stabilize the chocolate to viscosity changes by coating every particle of sugar with a thin film of cacao butter.
4. To increase the smooth taste of the material by rounding off the sharp edges of the sugar crystals.
5. To develop additional flavor by the oxidation of the cacao tannins and the interactions of the various ingredients; thus the sugar is slightly caramelized and slightly decomposed.
6. To reduce the tendency for fat "bloom" by the oxidation of a small quantity of cacao butter,¹⁰ as well as by the even distribution of the ingredients.

8. Chocolate Moulding

The final step in the processing of chocolate is the hardening of the material into various forms before being wrapped and labeled. The moulding operation is as im-

TABLE 43
APPROXIMATE COMPOSITION OF CHOCOLATE COATINGS^a

Coating	Chocolate liquor, %	Sugar, %	Whole milk solids, %	Skim milk or buttermilk solids, %	Total fat, %
Bitter	100	0	0	0	50-56
Bittersweet	80-95	5-20	0	0	40-50
Mild bittersweet	50-75	25-38	0	0	38-42
Dark sweet	25-45	40-50	0	0	34-42
Medium dark sweet	20-40	45-55	0	0	32-42
High-grade light sweet	15-25	40-50	0	0	34-49
Low-grade light sweet	5-15	55-68	0	0	31-39
Sweet milk	7-17	35-55	12 ⁺	0	28-39
Ice-cream coating ^b	9-29	29-39	12 ⁺	0-6	50-60
Skim milk, buttermilk, malted milk	7-17	35-55	0	12 ⁺	30-40

^a F. Fiene and S. Blumenthal, *Handbook of Food Manufacture*. Chemical Pub. Co., New York, 1942.

^b Ice-cream coatings can be made from any of the ordinary coatings by the addition of extra cacao butter.

portant as any of the other steps in the production of quality chocolate. Proper treatment at this point will produce a chocolate that has a good color, the desired snap or hardness, and a reduced tendency to bloom. As the chocolate comes from the finishers or conches, it is stored in large mixing tanks, or "jumbos," that will hold upwards of 10,000 pounds of finished goods. Sufficient cacao butter is added to produce a final mixture having a definite viscosity or, in some cases, a definite fat percentage.

Chocolate that will be used for coating purposes (see Table 43) is generally sold on a viscosity basis. Under uniform conditions, the viscosity of a coating will indicate the ratio of coating to center. Viscosity is a measure of thickness or consistency; usually the thinner the piece, the greater the covering power. Covering power is also affected by the fineness of the chocolate, its specific gravity, and its spread and adhesiveness. Greater coverage will be obtained by a finely milled chocolate, which adheres readily and has a high specific gravity.

(a) Viscosity

There are many instruments for determining viscosity. The one used by most chocolate manufacturers is the MacMichael viscosimeter. For comparative purposes, chocolate viscosities are determined under certain definite conditions. Viscosities reported in degrees MacMichael¹¹ must also specify the gage of the wire used,

TABLE 44
MACMICHAEL WIRE CONVERSION FACTORS

Wire gage	22	26	27	30	32
22	1	5.8	9.5	35.3	...
26	0.17	1	1.6	6.1	...
27	0.11	0.61	1	4.0	10
30	0.03	0.16	0.27	1	2.76
32	..	..	0.10	0.36	1

diameter of the bob, depth of immersion of the bob in the chocolate, r. p. m. of the holding cup, and the temperature at time of determination. (See Volume I, pages 19-23.)

Usually a No. 26 or a No. 27 wire (B & S gage) is used, with a 2-cm. bob, 4-cm. immersion, r. p. m. of 20, and a temperature of 100° F. for milk chocolate or 130° for vanilla chocolate and liquor. For a very thin or a very heavy chocolate, it may be

¹¹ J. Stanley, *Ind. Eng. Chem., Anal. Ed.*, 13, 398 (1941). According to Stanley the viscosity reading in degrees MacMichael can be calculated into poise readings by using a modified Couette equation:

$$\eta = \frac{OGd^4(1/a^2 - 1/b^2)}{128L\Omega l}$$

where η = viscosity, poise; O = angular torsion of wire, radians; G = modulus of rigidity of wire's metal, dyne per sq. cm.; d = diameter of wire, cm.; a = radius of inner cylindrical bob, cm.; b = radius of holding cup, cm.; Ω = angular velocity of MacMichael cup, radians per second; L = length of the inner cylindrical bob, cm.; l = length of wire, cm.

necessary to use a wire having a different gage. These readings can be converted to the standard gage being used, by means of the conversion factors given in Table 44. Readings on the MacMichael machine are directly proportional to the viscosity of the chocolate: a high reading indicates a high viscosity, etc.

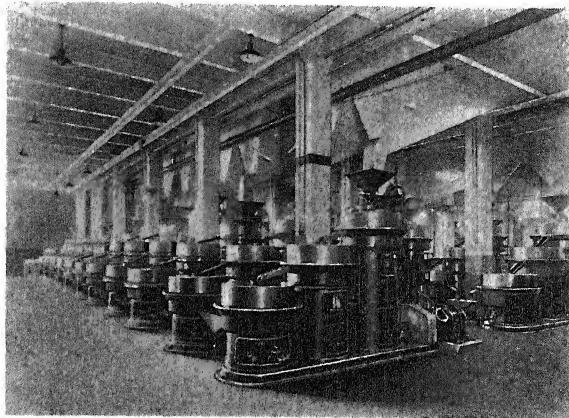


Fig. 134.—Battery of chocolate liquor mills. (See page 569.)
(Courtesy Hershey Chocolate Co., Hershey, Pa.)

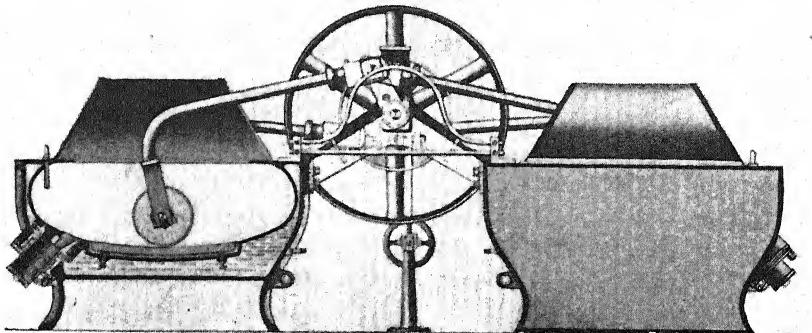


Fig. 135.—Four-tank conche.

Factors Influencing Viscosity.—The factors that will influence the viscosity of chocolate are cacao butter, lecithin, moisture, agitation, aeration, fineness, and temperature. Chocolate is a dispersion of finely divided cacao matter, and sugar, and sometimes milk solids, in cacao butter. Under true colloidal conditions, the solids will be coated with a thin film of cacao butter. The viscosity of the mass will depend upon the ease with which the particles can slide over one another. Increasing the fat content will decrease the viscosity until it approaches the viscosity of the cacao butter. Increasing the fineness of the ingredients will increase the surface area that will need to be coated, and result in a higher viscosity. The introduction of water

increases the viscosity of chocolate, as its presence tends to break the continuity of the fat-solid phases and decreases their freedom of movement. Between the temperature of 95 and 160° F., warming will thin dark chocolates and cause light sweet and milk chocolates, after a slight decrease in viscosity, to thicken considerably.¹¹ Aeration of chocolate also causes thickening. The addition of small quantities of lecithin to chocolates will reduce their viscosities. However, it should be noticed that the viscosity reducing effect of commercial lecithin is lowered as the viscosity of the chocolate de-

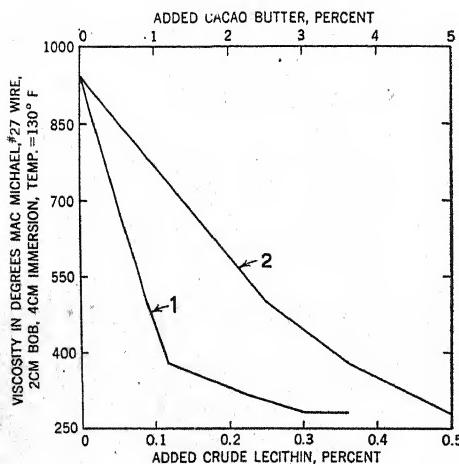


Fig. 136.—Curves showing the effect of (1) added lecithin, and (2) added cacao butter, to the viscosity of a chocolate coating.

creases. Actually, in the case of a very high fat content chocolate such as an ice-cream coating (viscosity, 8 to 12° M.), the introduction of lecithin produces no appreciable viscosity change. Freundlich¹² has shown that there is a relationship between the viscosity of a chocolate coating and its covering power.

Lecithin occurs naturally in living tissues and organs. It can be extracted by alcohol or ether and is obtained directly from such vegetable products as soybeans, peanuts, and corn. Lecithin is considered to be a phospholipid¹³ (see Volume I, page 100), and is found associated with a very similar compound called cephalin. Phospholipids are substances that contain fatty acids, nitrogen, and phosphorus. The name lipid

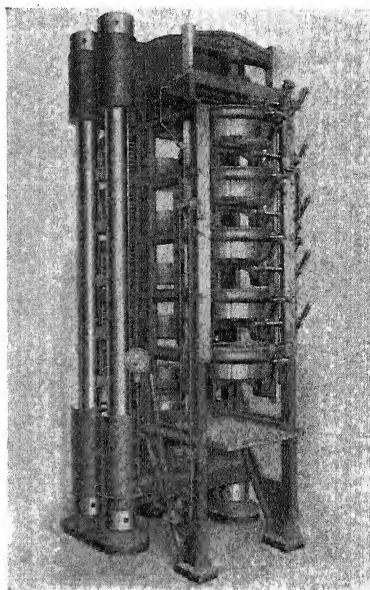


Fig. 137.—Five-pot cocoa press. (See page 579.) (Courtesy Fred S. Carver Co., New York, N. Y.)

¹² L. Freundlich, *Mfg. Confectioner*, 26 (Jan., Feb., 1940).

¹³ H. MacLean and I. S. MacLean, *Lecithin and Allied Substances*. Longmans, Green, New York, 1927.

distinguishes this type of substance from the lipoids, which are composed of natural fats and fatty acids.

Crude lecithin,¹⁴ as sold to the chocolate manufacturers, is a mixture of oil, lecithin, and lecithinlike bodies. A typical crude lecithin may have, with wide variations, the composition given in Table 45. Generally, the manufacturer of commercial lecithin may standardize the phosphorus content of his product, usually to have a minimum value of 2.4% phosphorus. The analytical values of a commercial lecithin are given in Table 46.

TABLE 45
APPROXIMATE COMPOSITION OF COMMERCIAL LECITHIN

	Per cent
Oil (peanut, corn, etc.).....	15
Lecithin.....	25
Cephalin.....	40
Galactolipids (contain no phosphorus).....	20

TABLE 46
TYPICAL ANALYSIS OF A COMMERCIAL LECITHIN

	Per cent
Acetone-soluble.....	45.48
Acetone-insoluble, alcohol-soluble.....	43.30
Acetone- and alcohol-insoluble, petroleum-benzene soluble.....	11.22
P ₂ O ₅	4.46

From these considerations it can be seen that it would be difficult to determine quantitatively the presence of added lecithin in chocolate by the usual analytical methods. It is the author's opinion that, in order to obtain a rapid and practical method for the determination of added lecithin, it is necessary to make use of some physical property of lecithin that is shared by the allied lecithin bodies. The "performance" or viscosity reducing power of the lipids suggests itself immediately as a basis for such a determination. Preliminary experiments indicate that the method is feasible.

The addition of lecithin to chocolate results in a saving of cacao butter, counteracts moisture, and stabilizes the chocolate. Figure 136 shows that the addition of 0.3% lecithin to a thick paste with an initial viscosity of 950° M. will have the same viscosity reducing effect as about 5% of cacao butter. The maximum reducing effect is usually obtained by the addition of 0.3% lecithin.

Although lecithin does not affect the viscosity of coatings containing more than 50% cacao butter, it is often used in such coatings. In the making of chocolate-covered ice-cream "pops", the moisture of the melting ice cream tends to thicken the chocolate; since lecithin is a hydrophilic colloid it will absorb the water and prevent its thickening action. There is a limit to this protection; Erb¹⁵ found that lecithin will

¹⁴ Commercial lecithins on the market are sold under the trade names of Yelkin and Lexin.

¹⁵ J. Hoffman Erb, *Ice Cream Trade J.*, 37 (May, 1941).

prevent this increase in viscosity of ice-cream coatings provided they contain not more than 1.5% moisture.

(b) *Tempering*

To obtain a fairly stable system in the finished goods it is important that the materials are finely divided and well mixed by proper refining or by a combination of refining and conching; that all the cacao butter is melted before moulding; that this is accomplished during tempering; and that during the moulding, or solidification, of the chocolate the cooling process is not too slow or too rapid. This can be controlled by adjusting the temperature of the cooling tunnels and the time of cooling.

The tempering of chocolate is necessary because one of its ingredients, cacao butter, is a mixture of fats of different melting points and consequently does not have a definite melting point. The individual fats also exert an influence on the melting points and solidifying points of the other fats. Since cacao butter contains both low melting fats and high melting fats, it is necessary that conditions be so adjusted that all the fat is liquid when the mixing takes place and that all of the butter is hardened when the chocolate is moulded. Otherwise, unequal distribution of the cacao butter fractions will take place with a resulting tendency of the finished chocolate to bloom. The eating quality of the finished material will also be impaired. To insure proper tempering, the chocolate is stirred at 120 to 130° F., according to the type of chocolate being treated, until it attains a uniform smoothness. It is then cooled to 87.5 to 90.5° F.¹⁶, depending on plant conditions before moulding.

The final hardening of the chocolate must also be carefully watched, because of the cacao butter content and the poor heat conductivity of chocolate. The ideal moulded chocolate should contain small crystals of cacao butter. If the goods are cooled too slowly, to insure solidification of all of the fat, large crystals may result. If cooled rapidly, an unstable, supercooled liquid cacao butter will be obtained. If it crystallizes out, the liberated latent heat of crystallization will melt the low melting fractions of the fat, redistribute them, and cause fat bloom. Good moulding conditions can be obtained by using a countercurrent cold air draft in the cooling tunnel, hardening at a temperature of from 60 to 62° F. for 45 to 50 minutes.

(c) *Storage*

Care must be taken in the storage of chocolate because it will become affected by external conditions. The two more important factors are humidity and temperature. If chocolate is stored in a room with a high degree of humidity, moisture will condense on it and dissolve some of the sugar in the mixture. On later evaporation of the water, the sugar crystals will appear as a gray excrescence on the surface of the chocolate. This is called sugar bloom. The presence of a stabilizer such as lecithin has an inhibiting effect on this phenomenon. Proper working of the chocolate and storage of the product will also prevent bloom.

¹⁶ T. Glendenning, *Mfg. Confectioner*, 23 (Aug., 1937).

If the storage room is too warm, the cacao butter in the mass will melt and expand. The less dense fat will rise to the surface of the chocolate and on later cooling will solidify there, forming a grayish-white film that is greasy to the touch. This is known as fat bloom. Proper tempering and storage will inhibit fat bloom. Well-conched chocolate is less prone to undergo this defect.

(d) *Enrobing*

In 1939, over 200,000,000 pounds of chocolate were used in the United States by candy manufacturers as a covering for various types of centers. Up until 1901, coating work was performed by hand, a slow and expensive process. The introduction at that time of the enrober, or mechanical hand dipper, revolutionized the chocolate and candy industry. It cut down on the cost of production of covered confections and encouraged their sale.

TABLE 47
USES FOR CHOCOLATE, INCLUDING COATINGS FOR SPECIFIC CENTERS^a

Butter creams—1:2:3	Hand rolls—1:2	
Candy bars—4:5:6:8	Ice cream bars—7:9	
Caramels—4:5:8	Italian creams—2	
Chocolate bars—4:5:6	Jelly centers—4:9	
Chocolate ice cream—1	Marshmallows—2:3:4:5:8	
Chocolate "pops"—7:9	Nougats—3:4:5:6:8:9	
Chocolate sirups—1	Nutmeats—4:5:6:8	
Coconut creams—4	Nut creams—3:4:9	
Cordials—2:3	Peppermint creams—1:2:3	
Culinary products—1	Raisins, dates, and figs—4:6:8	
Frappe—2:9	Sponge centers—4:9	
Fruit-flavored creams—4:9	Vanilla creams—4:6:8:9	
Fudge—1:2:3:5:8		
CODE		
1. Chocolate liquor	4. Medium dark coating	7. Ice cream coating
2. Bittersweet coating	5. Light sweet coating	8. Skim milk coating
3. Dark sweet coating	6. Milk chocolate	9. Imitation coating ^b

^a Adapted from F. Fiene and S. Blumenthal, *Handbook of Food Manufacture*. Chemical Pub. Co., New York, 1942.

^b Imitation coatings are mixtures of sugar, cocoa, and substitute fats such as coconut oil, coconut stearins, illipe oil, etc., with or without flavoring added. These are used for medicated preparations where a higher melting chocolate is desired.

Increased consumption of covered centers also led to an increased demand for chocolate, and upset the chocolate manufacturer's balance between chocolate and cocoa production. At one time, the main product of a chocolate and cocoa factory was cocoa powder; today chocolate has taken its place.

The enrober makes a very high output possible, a modern machine producing as much as 40 tons of confection per day. These candies compare favorably with hand-dipped work.

The enrober in general use is based on the original designs of Magniez, and was introduced by the Savoy-Jeanjean Company of Paris. The machine consists essen-

tially of a series of conveyors that will carry the centers through the different steps. The centers are placed on an endless track leading into the enrober. They first are "bottomed" by being passed over a shallow layer of chocolate that covers the bottom of the confection with a thin film. The film of chocolate is hardened by a passage over cooling tables. The centers are then fed into the enrober proper, where a curtain of chocolate flows over them and the final covering takes place. The covered pieces pass over shaker tables where a stream of hot air, assisted by the shaking action, removes the excess chocolate. The coated pieces are then passed through the cooling tunnels. The same care must be taken in the coating of candy as in the moulding of chocolate. The chocolate must be properly tempered and cooled in order to obtain its best qualities.

The chocolate used for coating purposes should blend with the center; for example, an extremely sweet cream center should be covered with a dark semisweet chocolate. In Table 47 a list of selected coatings for different centers is given.

9. Federal Standards and Definitions

Cocoa nibs, "cracked cocoa": Roasted or dried cacao beans, broken and freed from germ and from shell or husk.

Chocolate, plain chocolate, chocolate liquor, chocolate paste, bitter chocolate liquor: The solid or plastic mass obtained by grinding cacao nibs. It contains not less than 50% cacao fat and on the fat- and moisture-free basis not more than 8% total ash, not more than 0.4% ash insoluble in hydrochloric acid, nor more than 7% crude fiber.

Sweet chocolate, sweet chocolate coating: Chocolate mixed with sugar and/or dextrose, with or without the addition of cacao butter, spices, or other flavoring materials. It contains on the moisture-, sugar-, and fat-free basis, no greater per cent of total ash, acid-insoluble ash, or crude fiber, respectively, than is found in moisture- and fat-free chocolate.

Milk chocolate, sweet milk chocolate: The product obtained by grinding chocolate with sugar and/or dextrose, with the solids of whole milk, or the components of milk solids in proportions normal for whole milk, and with or without cacao butter, and/or flavoring materials. It contains not less than 12% of milk solids.

Dutch-process chocolate, "alkalized chocolate": See under the standards for cocoas on page 582.

II. MANUFACTURE OF COCOA

Cocoa, as a beverage, is an important addition to the diet because of its food value and slightly stimulating effect. In 1941, over 7,000,000 pounds were used by the confectionery industry in the making of candy. The bulk of the cocoa produced, however, is sold for food purposes.

The preliminary processes in the manufacture of cocoa are similar to those mentioned in the making of chocolate. The raw beans are cleaned, roasted, cracked, and freed from shell and germ. Cacao beans, destined for cocoa powder, are usually given a slightly higher roast than those used in the preparation of chocolate. The roasted nibs are transferred to the liquor mills to be converted to chocolate liquor. The grinding, in this case, is very thorough. Modern practice in the grinding of nibs includes the use of disk mills, such as the Bausmann type. These mills, being water-

cooled, prevent overheating and have a much larger output than the regular triple grinding stones. The disk mills are more durable and require less replacement and care. The chocolate liquor is then pumped to hydraulic presses where most of the cacao butter is removed. This is necessary because ordinary chocolate liquor, which contains over 50% fat, would not only make an excessively rich beverage but would have some of its fat separating in the cup.

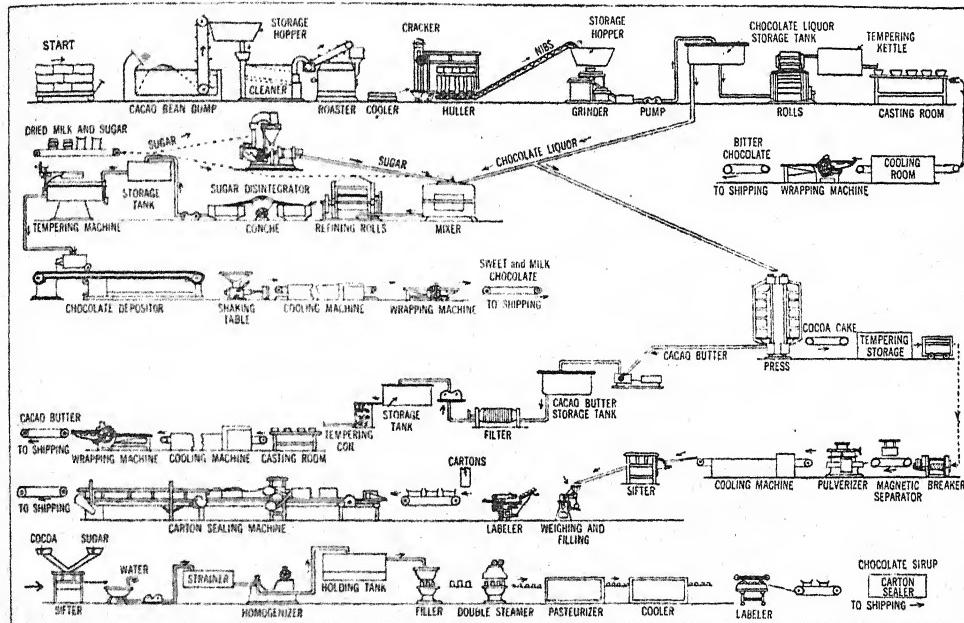


Fig. 138.—Cocoa and chocolate manufacture. (Courtesy Rockwood Chocolate Co., N. Y.)

The hydraulic presses are usually the vertical piston type. Giant presses using horizontal pistons producing pressures over 3 tons per square inch are also in use. The Carver hydraulic press (see Fig. 137, p. 574) consists of a series of hollow metal pots with perforated beds. Each press contains five of these steel sieves that are fitted to a vertical column and can be run in and out of the frame on rails. By means of control valves the pots are automatically filled; the liquor charge per five pots is 250 pounds. The closing of the pots is also automatic and is accomplished by the use of strong springs. Pressure is applied to the pots in two stages. First a lower pressure of from $\frac{1}{2}$ to $\frac{3}{4}$ tons per square inch, which can be gradually increased to 3 tons per square inch. The amount of fat remaining in the press cake can be adjusted to suit the demands of the manufacturer, although it is not practical to press for a residue having less than 7% cacao butter. The latest type of Carver press is equipped with fine metal plates that obviate the need of cloth filter pads during the expression

of the fat. The residue press cakes are automatically ejected from the pots and are ready either to be converted into cocoa or to be solvent-extracted for the remaining cacao butter.

The press cake, which remains after the extraction of the fat, contains from 25 to 8% of cacao butter, depending upon the time and the force of the pressing. To be converted into cocoa powder, the cakes must be cooled and then broken into small pieces. The broken cakes are passed over a magnetic separator to remove any metallic particles that may be present, and are then ground to a fine powder. This is accomplished in a micropulverizer. Before the cocoa is ground it must be cooled, or the additional heat of the grinding process will produce a powder that will have a poor color. The powdered cocoa is sifted either through silk or by an air flotation process and is ready to be packed. Automatic assembly lines are used that will not only weigh out the correct amount of cocoa into a container, but will also build up the can from cardboard and tin, paste a label on each can, and deliver, to the waiting attendant, the filled can ready for shipment.

1. Cocoa Classifications

Cocoas may be classified according to their fat content, but the two main types are natural and "Dutched" cocoas.

The name "Dutched" is derived from the fact that this type of cocoa is processed by a method that originated in Holland. The removal of the fat, as well as the fine grinding of the cocoa powder, leaves the finished product much lighter than chocolate. The attempts made to darken the powder led to the "Dutching" process. Although the first reason for using the method was to darken the cocoa, it was later claimed that "Dutching" increases the solubility of the powder. Bloomberg¹⁷ shows that, while there is no doubt that a processed cocoa will form a better suspension than natural cocoa and will have less of a tendency to settle out from solution, it is not more soluble in water than the natural cocoa.

"Dutching" gives the cocoa manufacturer better control over the color of his products. There is also a gain in strength and richness even though the treatment may not improve the cacao aroma. There are various methods used to treat the cocoa. The usual "Dutching" is by means of such alkaline substances as the carbonates, bicarbonate, or hydroxides of sodium, potassium, or ammonium. Attempts have been made to develop this treatment by means other than the addition of chemicals, including the action of steam under pressure; wetting the cocoa and allowing it to ferment; or simply wetting the powder and then drying it.

When treating with alkalies, which is the usual method, the procedure is to add a solution of the chemical in water to the partially roasted and cleaned nibs. The roasting process is continued until the excess water has evaporated and the nibs have the desired color. The treated material is then ready for grinding and pressing in the usual way.

¹⁷ E. Bloomberg, U. S. Dept. Agr., *Bull.* 666 (1918).

2. pH of Cacao Products

Cacao products have varying pH values. Natural chocolate liquor, cocoa powder, and fat-free cocoa matter all have approximately the same pH. In other words, the pH is not affected very appreciably by the percentage of cacao butter in the product. Natural cacao products have a pH ranging from 5.2 to 6.0. This variation can be attributed to the variable amounts of tartaric, acetic, and citric acids, protein effects, and the soluble plant carbohydrates which are present. Although considerable acetic acid is volatilized with steam during the roasting process, the change in pH because of roasting may be no more than 0.1 to 0.2 on the pH scale. Steam roasting may also hydrolyze certain complex plant constituents actually to liberate more nonvolatile plant acids than are removed in the roasting process.

TABLE 48
COCOA POWDERS AND THEIR USES^a

Cocoa	Fat content, %	Remarks	Uses
Semicocoa, crumbles, etc.	32-45	Good flavor	Ice creams, icings
High-quality	25-32	Made from select quality beans	Ice creams, beverages, icings, layer cakes, sirups
Breakfast	22	.....	Natural: drinking sirups "Dutched": biscuits, devil's food cake, fudge
Semidry	15-18	.....	Natural: malted milk mixtures, cocoa milk drinks, chocolate desserts, sirups
Dry	10-12	Low-cost product	Natural: milk drinks, cocoa-skim milk mixtures, icings "Dutched": devil's food cake, extracts, baking
Extra dry	6.5-8	Limit by hydraulic press	Substitute or imitation coatings, dusting powder in confectionery industry
Solvent-extracted	0.5-3	No chocolate flavor; high moisture content	Similar to extra dry; also, theobromine extraction
By-product	5.5-11	Anderson expeller; obtained from fines	Fertilizer, theobromine extraction, cattle feed
Prepared		Cocoa with added sugar, etc.	Instant chocolate and milk drinks

^a Adapted from F. Fiene and S. Blumenthal, *Handbook of Food Manufacture*. Chemical Pub. Co., New York, 1942.

Insofar as Dutch-process cocoas are concerned, the pH of cacao products is modified in proportion to the amount and type of alkali used. Generally, any free acid which is present in the material is neutralized completely. Additional quantities of alkali react with the protein and carbohydrate material to produce water-soluble compounds. This, however, is more than made up for by the fact that the alkali treatment exercises an inhibitory effect on the solution of the nonnitrogenous substances which are normally soluble in water.

If very strong alkalies are used, and they are not mixed in slowly and uniformly, a

saponification reaction may take place with the formation of traces of soap. The tannin complexes are modified, and a trace of the alkali may be absorbed by the theobromine to form a theobromine salt.

Dutch-process cocoas have a normal *pH* of 6.0 to 8.8. This need not indicate the presence of free alkali. It may show that alkali salts are present which form fairly well-buffered solutions in the range above 7.0. The higher the *pH*, above 7.0, the more suitable the product is for baking and cooking, and for ice cream. Mild "Dutched" cocoas (*pH* 6.0-6.8) are used for soft drinks, beverage cocoa, and chocolate icings. Many manufacturers preparing sweet milk cocoa powders use the cocoas having a *pH* of 6.8 to 7.8.

Table 48 lists the various cocoa powders and gives their particular uses.

3. Cocoa Standards

Cocoa, powdered cocoa: Chocolate deprived of a portion of its fat and pulverized. It contains, on the moisture- and fat-free basis, no greater per cent of total ash, acid-insoluble ash, or crude fiber, respectively, than is found in moisture- and fat-free chocolate.

"*Breakfast cocoa*": Cocoa which contains not less than 22% of cacao fat.

Sweet cocoa, sweetened cocoa: Cocoa mixed with sugar and/or dextrose. It contains not more than 65% of total sugars in the finished product, and, on the moisture-, sugar-, and fat-free basis, no greater percent of total ash, acid-insoluble ash, or crude fiber, respectively, than is found in moisture- and fat-free chocolate.

Sweet milk cocoa: The product obtained by grinding cocoa with sugar and/or dextrose, with the solids of whole milk, or the components of milk solids in proportions normal for whole milk. It contains not less than 12% of milk solids.

"*Dutch-process*" chocolate, "*alkalized*" chocolate, and "*Dutch-process*" cocoa, and "*alkalized*" cocoa: Modifications, respectively, of chocolate and cocoa in that in their manufacture an alkali carbonate or other suitable alkaline substance has been employed. In the preparation of these products not more than 3 parts of potassium carbonate, or the neutralizing equivalent thereof in other alkaline substances, are added to each 100 parts by weight of cacao nibs. The finished products conform to the standards for chocolate and cocoa, respectively, due allowance being made for the kind and amount of alkaline substance added.

III. MANUFACTURE OF CACAO BUTTER

As a result of an interesting economic situation, relating to the popular demand for chocolate, cocoa has become a by-product, with cacao butter the main product. In the preparation of cocoa powder, the manufacturer prefers to use a blend of high-quality beans; when cacao butter is the material sought, economy makes him utilize the cheaper grades of beans and treat them drastically during the roasting and grinding steps so as to prepare the ground nibs for the most complete extraction of cacao butter.

1. Methods of Extraction

The three methods of butter extraction are: expression of the fat by hydraulic pressure, solvent extraction, and expeller. Regardless of the method of extraction it must be recognized that the quality of the cacao butter obtained depends upon the grade of the bean used. Fully ripened, well fermented, properly dried and stored beans will

give a higher grade of fat than unripe, poorly fermented, or moldy beans. Although a good grade of cacao butter can never be obtained from inferior beans, it is possible that poor manufacturing methods may produce a low-quality butter from high-grade materials.

(a) *Expression by Hydraulic Pressure*

This method has been described in the preparation of cocoa powder (see page 579). About 90% of the total fat in the chocolate liquor can be removed by this process, leaving a press cake containing from 6 to 8% cacao butter. The extracted butter contains albuminous material and a small amount of cocoa matter. It is necessary to filter the fat before it is moulded. Cacao butter must be tempered before being moulded; as a matter of fact, the tempering of chocolate is necessary because of the presence of the cacao butter. An ideal cacao butter should have a firm, hard texture when solidified; when melted, it should have a clean flavor and a bright clear color.

(b) *Solvent Extraction*

In this process, the fat is dissolved from broken up press cake, crushed nibs, or expeller cake. The fatty material is charged into a series of extraction tanks fitted with reflux condensers. The principle of extraction used is based on countercurrent operation. Fresh solvent is introduced into the tank containing the cocoa matter that is most nearly exhausted, flows through the several tanks in series, and is finally withdrawn from the tank which has been freshly charged. The material can be charged and discharged from one tank at a time. The extraction cells are fitted with heaters so that the extraction can be carried out while the material is warmed. The fat-saturated solvent is then distilled through a fractionating column. In order to minimize the loss of solvent, any air or uncondensable gas escaping from the solvent recovery condenser is usually scrubbed through oil washers or passed over an absorbent material such as charcoal or silica gel. The solvents used may include petroleum benzene or trichloroethylene (Westrosol). Petroleum benzene has the advantages of being cheap, having a minimum tendency to dissolve nonfatty material, and of being easy to remove from the extracted fat. Its chief disadvantage is that it is inflammable. Trichloroethylene, while expensive, is noninflammable. Solvent-extracted cacao butter requires careful aftertreatment to remove the final traces of the solvent and any other components of the cacao bean that have come over with the fat. If a good grade of bean is defatted by this method, and proper treatment is given to the extracted butter, it will compare favorably with fat obtained by the hydraulic press.¹⁸ Almost 100% of the fat can be removed by solvent extraction.

(c) *Expression by Expeller*

The expeller is essentially a screw press, designed in 1903 by Anderson. It consists roughly of 2 worms running the length of a slotted barrel. One end of this barrel is

¹⁸ E. Benyon, *Mfg. Confectioner*, 16 (Feb., 1930).

closed by an adjustable plate. The first worm feeds warmed and broken cacao beans to the other, which in turn forces them through the spaces between the plate and the barrel. Two designs are used: In one, the screw operates in a gradually narrowing barrel; in the other, the diameter of the barrel is constant, but the size of the worm becomes progressively larger toward the exit end. In either case, the action of the screw causes increasing pressure on the material as it passes through the expeller. Continuous operation is possible with the Anderson expeller which is designed to handle about 100 tons of material per 24-hour day. It can also be adjusted to yield high- or low-fat expeller cakes. Because the expeller is used in the pressing of cacao butter from raw beans, sweepings, high shell content nibs, and other waste material, the expeller butter is usually of poor quality. About 90-95% of the total fat content is removed by the expeller. Usually the remaining cacao butter is removed from the expeller cake by solvent extraction.

2. Cacao By-Products

These consist of shells and, in recent years, cocoa press cake and solvent-extracted cocoa. About a quarter of these products are used for fertilizer, the rest in making cattle feed (experiments indicate that it may depress the milk flow of dairy cattle), for the extraction of theobromine, and for fuel (usually in the chocolate manufacturer's factory).

3. Confectionery Fats

According to Hilditch,¹⁹ confectionery fats should have the following qualities: digestibility equal to that of dairy butter; and a physical texture which is not greasy, which is hard and "snappy" or brittle (melting point is not above 37-38° C.), and which is permanently bright and clear at the surface. The more important natural fats possessing these properties are cacao butter, Borneo tallow, illipe butter, and *Allanblackia* fats. This group of seed fats have as their major components palmitic, stearic, and oleic acids, with stearic acid typically prominent in most of them—the only instance in which stearic acid is a major acid component in fats of the vegetable kingdom.

Because these fats are expensive, other fats are substituted for them, in whole or in part. The substitutes include hardened coconut or palm-kernel oils and babassu or murumuru fats. Sometimes certain portions of edible coconut or palm-kernel oil ("stearin") may be added to cacao butter. The presence of these fats in chocolate and confectionery can be detected by determinations of the physical constants of the extracted fat. It is difficult to detect the presence of Borneo tallow (erroneously called illipe butter) unless special tests for its presence is made. The Halphen test, as modified by Bolton and Revis,²⁰ gives good results.

¹⁹ T. P. Hilditch, *Industrial Chemistry of the Fats and Waxes*. 2nd ed., Ballière, Tindall & Cox, London, 1941.

²⁰ E. R. Bolton and C. Revis, *Analyst*, 38, 201 (1913).

TABLE 49
CACAO BUTTER AND RELATED FATS^a

Fat	Source	Habitat	Approx. annual prod., 1000 tons	Application	Fat content, %
Coconut	<i>Cocos nucifera</i> , <i>C. butyracea</i>	Southern tropical islands, Brazil	500-650	Vegetable butters	63-65 (dried copra)
Palm-kernel oil	<i>Elaeis guineensis</i> varieties	West Africa, Mala-ya, Dutch East Indies	225-275	As coconut oil sub., soft edi-ble fats, soaps	45-50 (kernel)
Palm oil	<i>Elaeis guineensis</i> varieties	West Africa, Mala-ya, Dutch East Indies	300-400		30-60 (fruit pulp)
Murumuru fat	<i>Astrocaryum murumuru</i>	Brazil		Edible fats	36-42 (kernel)
Babassu	<i>Attalea funifera</i>	Brazil			63-70 (kernel)
Cacao butter	<i>Theobroma cacao</i>	West Indies, Central and South America, West Africa	100	Confectionery fats	50-55 (seeds)
Borneo tallow	<i>Shorea</i> species	Malaya, Borneo	.....	Cacao butter substitute	20-30 (seeds)
Mkanyi tallow	<i>Allanblackia</i>	West Africa	Low		67-70 (kernels)
Mowrah butter (illipe)	<i>Bassia latifolia</i>	Northern India, East Indies	50-100	Druggists' prepara-tions, can-dles, soap	50-55 (seed)

^a T. P. Hilditch, *Industrial Chemistry of the Fats and Waxes*. 2nd ed., Baillière, Tindall & Cox, London, 1941.

TABLE 50
PHYSICAL CONSTANTS OF CACAO BUTTER AND RELATED FATS^a

Fat	Sp. gr. (water at 15°)	Set- ting point, °C.	Melt- ing point, °C.	Sapon. value	Sapon. equiv.	Iodine No.	Refrac. index	F. F. A., %
Coconut	0.926/15° 0.874/99°	19-23	24-28	250-260	216-225	8-10	1.443/60°	2-5 ^b
Palm-kernel oil	0.930/15°	19-24	25-30	243-250	225-230	15-18	1.443/60°	2-7 ^b
Palm oil	0.921- 0.925/15°	31-39	27-30	196-210	256-285	51-58	1.451/60°	4-27 ^c
Murumuru fat	0.920/15°	30-32	34-35	237-242	231-237	11-12	1.452/40°	0.6 ^b
Babassu	0.869/15°	22-23	22-26	247-253	221-227	12-16	1.449/40°	0.5 ^b
Cacao butter	0.970/15° 0.858/98°	23-26	33-35	192-195	286-292	35-42	1.450/60°	0.5-1.5 ^d
Borneo tallow	0.856/100°	22-30	28-37	192-196	285-292	30-33	1.456/60°	4-15 ^d
Mkanyi tallow	0.930/15°	30-38	40-45	187-192	292-300	38-44	1.458/15°	1-10 ^d
Mowrah butter (illipe)	0.920/15°	18-25	23-31	187-194	284-299	58-63	1.460/40°	3-20 ^d

^a T. P. Hilditch, *Industrial Chemistry of the Fats and Waxes*. 2nd ed., Baillière, Tindall & Cox, London, 1941.

^b Calculated as lauric acid.

^c Calculated as palmitic acid.

^d Calculated as oleic acid.

Tables 49 and 50 give physical constants and other information about cacao butter and its related fats. Table 51 gives the chemical composition of these confectionery fats. See also pages 581-583 of Volume I.

TABLE 51
CHEMICAL COMPOSITION OF THE CONFECTIONERY FATS^a

Acids	Coconut oil	Palm-kernel oil	Murumuru fat	Babassu	Cacao butter	Borneo tallow	Mkanyi tallow	Mowrah butter
Saturated:								
Caproic	Trace	..	..	Trace	..	..	..	..
Caprylic	7.8	2.7	1.1	6.5	..	..	..	..
Capric	7.6	7.0	1.6	2.7	..	..	..	..
Lauric	44.8	46.9	42.5	45.8	..	..	..	..
Myristic	18.1	14.1	36.9	19.9	..	..	..	..
Palmitic	9.5	8.8	4.6	6.9	24.4	18.0	3.1	23.7
Stearic	2.4	1.3	2.1	..	35.4	43.3	52.6	19.3
Arachidic	..	..	..	..	..	1.1	..	..
Unsaturated:								
Oleic	8.2	18.5	10.8	18.1	38.1	37.4	44.1	43.3
Linoleic	1.5	0.7	0.4	..	2.1	0.2	0.2	13.7

^a T. P. Hilditch, *Industrial Chemistry of the Fats and Waxes*. 2nd ed., Baillière, Tindall & Cox, London, 1941.

IV. MANUFACTURE OF CONFECTIONERY

The fundamental processes used in the making of the countless varieties of candy are essentially the same. This is because, in most cases, the chief ingredient is cane or beet sugar. To obtain successful results in the manufacture of confectionery, it is necessary to be familiar with the factors involved in the "physical" changes of the sugars and to be able to control these factors. Most candies are sugar mixtures consisting of a solid or crystalline phase and a liquid or noncrystalline phase. The varieties of candy are made possible by regulating the proportions of these two phases. Stanley²¹ gives the following classification for candies:

Candies in which sugar is present in the form of crystals:

- (a) Large crystals—rock candy.
- (b) Small crystals—fondant and fudge (crystals are so small that their presence may not be detected by feel or by the tongue).

Candies in which the sugar is present in an uncryallized form:

- (a) Brittles—peanut, one type of nougat.
- (b) Hard candies—also some taffy, toffee, glacéd fruits and nuts, butterscotch.
- (c) Soft candies—caramels.

Candies given some special texture by the addition of some colloidal material such as gelatin, egg white, gum arabic, pectin, or starch:

- (a) Spongy candies.
- (b) Gummy candies—gumdrops, marshmallows, pectin candies.

²¹ L. Stanley and J. A. Cline, *Foods: Their Selection and Preparation*. Ginn, Boston, 1935.

Fondant Manufacture

One of the simplest sugar mixtures to be considered in the making of candy is the fondant. Since its manufacture is representative, it can be used to illustrate the important factors in sugar cooking.

The main ingredients in the making of fondants are sugar, water, and a "doctor," usually cream of tartar or invert sugar. The procedure involves dissolving the sugar completely in water, adding the doctor, and then cooking to the proper temperature (see Table 52). The supersaturated solution is carefully cooled. Crystallization is then induced by the beating or whipping of the solution. Meanwhile a sirup "bob" has been prepared by mixing sugar and water together and heating them to form a thin sirup. This cooled stock sirup is added to the crystallized batch in the beater for thin-

TABLE 52
CANDY TEMPERATURE CHART^a

Products	Stage of concentration desired	Sirup temp. at sea level (indicating concn. desired)		Behavior at stage desired
		° F.	° C.	
Sirup	Thread	230-234	110-112	The sirup spins a two-inch thread when dropped from fork or spoon
Fondant Fudge Panocha Caramel	Soft ball	234-240	112-115	The sirup when dropped into very cold water forms a soft ball which flattens on removal
	Firm ball	244-248	118-120	The sirup when dropped into very cold water forms a firm ball which does not flatten on removal
Marshmallow Nougat Popcorn ball Salt-water taffy	Hard ball	250-265	121-130	The sirup when dropped into very cold water forms a firm ball which is hard enough to hold its shape, and yet is plastic
Butterscotch Toffee	Soft crack	270-290	132-143	The sirup when dropped into very cold water separates into threads which are hard but not brittle
Brittle Glacé	Hard crack	300-310	149-154	The sirup when dropped into very cold water is hard and brittle
Barley sugar Caramel	Clear liquid Brown liquid	320 338	160 170	The sugar liquefies The liquid becomes brown

^a Terminology Used in Food Preparation. Am. Home Economics Assoc., Washington, D. C., 1936.

ning purposes. The beating is continued for a few minutes to insure a thorough mixing. The finished fondant consists of minute sugar crystals dispersed in a liquid phase which is a saturated sugar solution. This colloidal system is sufficiently fluid to have plasticity and surface tension and exhibit capillary phenomena.

Because the texture is of such importance, the making of the fondant is concerned, primarily, with the control of the crystallization or the graining of the supersaturated sugar solution. Careful studies indicate that the kind of crystals produced depends on:

1. The degree of inversion of the cane sugar produced by the "doctors."
2. The presence of other added sugars such as dextrose or invert sugar.

3. The time and temperature of the cooking.
4. The manipulation of the fondant mixture.
5. The addition of colloidal ingredients such as egg albumin.
6. The "curing" or ripening of the fondant.

(a) *Use of Doctors*

Doctors are chemicals added to sugar mixtures to inhibit the graining of the saturated sugar solution. They fall into two classes, namely, chemicals that will hydrolyze a portion of the sucrose to form invert sugar, and substances that will directly slow down the rate of crystallization. Cream of tartar (potassium acid tartrate) and acetic acid (vinegar) belong to the first type. Invert sugar, dextrose (glucose, commercially known as cerelose), and corn sirup belong to the second type. Invert sugar and dextrose inhibit the crystallization of the sucrose, the resulting slower rate of precipitation producing small sugar crystals. If an excess of invert sugar is added or produced during the reaction, the finished fondant will be too soft. When making candies of this type, it is important that the water used be neutral and not hard; otherwise it will counteract the effect of an acid doctor.

(b) *Other Factors*

Dextrose.—Corn sugar and corn sirup are used as doctors, as mentioned above. In addition, their use produces a liquid phase with a higher sugar concentration than is possible in an all-sucrose fondant. Because of this increased sugar content, there is less chance of the fondant's fermenting or drying out.

Sugar Boiling.—The purpose in cooking the sugar solution is to obtain a definite concentration of the sugar in water. This point is determined by the temperature of the solution and the period of cooking at that temperature. Many candy workers use a rule-of-thumb method which involves the physical properties of the solution at a certain temperature and concentration. For accurate work, a candy thermometer should be used. Table 52 gives the temperature and properties of solutions for different candy work. For fondant work, a time period of 10 to 15 minutes at 236° F. will produce a soft, creamy product. A shorter cooking period will yield a very sweet mass because of the larger quantity of dissolved sugar.

Manipulation.—Since the fondant is formed by the graining of sugar from a supersaturated solution, proper precautions should be taken to prevent premature crystallization. All of the sugar must be dissolved before the boiling begins. The presence of a crystal of undissolved sugar will act as a nucleus about which other crystals will form. The solution should be stirred slowly during boiling to prevent caramelization, but not after boiling or crystallization may result. Slow boiling is recommended because the agitation caused by the bubbles often causes precipitation. The fondant mixture should not be handled more than necessary during its cooling. In order to obtain the desired creamy fondant, the solution should be quite cool before being beaten, and the beating process should last for 3 to 5 minutes. Air beating will produce quicker crystallization.

Colloidal Ingredients.—The addition of certain colloids such as egg white and gelatin will inhibit the crystallization rate and help produce smaller crystals.

Ripening.—This process consists of allowing the finished fondant to stand for 24 hours or longer. It allows the mixture to become more moist by a redistribution and equalization of the water in the fondant through diffusion and capillary action.

Invertase.—Many fondants and creams which are later covered with chocolate must be firm and solid when coated, but require soft fluid centers when eaten. This may be accomplished by the use of a delayed-action inversion, caused by the addition of invertase to the fondant mixture. Invertase is an enzyme obtained from yeasts and fungi. Since its action is slow at low temperatures, the extent of creaming can be controlled by refrigerating the product. After the fondant has been coated, later action of the invertase will invert the sucrose; the formation of invert sugar will change the confection's firm center to a creamy consistency.

V. MANUFACTURE OF CHEWING GUM

It is interesting to note, in this period of scarcities and substitutions, that the production of the modern chewing gum had its birth in an attempt to find a rubber substitute. In 1860, while unsuccessful efforts were being made to vulcanize the sap of the sapota tree, it was discovered that the desiccated sap had properties similar to spruce and cherry gum. The chicle was found to have the proper plasticity and to be insoluble; not only would it mix well with flavors, but it would retain them. Today the basis of American-made chewing gum is this chicle.

Chicle consists of the partially evaporated milky juice of the *Achras sapota*, an evergreen tree indigenous to Mexico, Central America, South America, and the West Indies. The sap is obtained by scoring the bark of the tree in connected parallel cuts in a kind of herringbone pattern down the length of the unbranched trunk. The method is very similar to the one followed in obtaining the sap of the pine trees in the preparation of turpentine. The collected liquid is boiled, filtered, and allowed to cool in moulds holding from 25 to 50 pounds of the chicle. The blocks, when ready for shipment, contain about 33% of water.

As the chewing gum industry used over 80,000,000 pounds of raw materials in 1939 (including 8,500,000 pounds of chicle), and produced goods having a value of about \$61,000,000, it can be seen that modern methods must be used in meeting the great demand for this candy. Although the preparation of chewing gum is not so complex as the preparation of other confections, intricate machinery is used for the processing and wrapping of the gum.

The blocks of chicle, as received by the manufacturer, are broken into small pieces, melted, filtered, and then mixed with the various ingredients used in the making of the chewing gum. It has been calculated that 13 pounds of purified chicle will make about 5000 pieces of gum. A typical formula²² would be as follows: gum chicle, 3½ lbs.; balsam tolu, 2 oz.; sugar, 12 lbs.; water, 3 parts; with flavoring extract as re-

²² H. M. Hoar, U. S. Dept. Commerce, *Trade Information Bull.* 197 (1924).

quired. It is interesting to note the use of corn sugar, or dextrose, as an inhibitor or "doctor," to prevent the crystallization of the sucrose. The mixed ingredients are kneaded well, cut into 12-pound pieces, and then rolled into thin sheets. The strips are cut to the required size dried, and wrapped.

Because of the cost of the chicle many attempts have been made to find suitable substitutes. As yet, none have been found that can compare satisfactorily with chicle when used solely as a base for a chewing gum. Some substitutes, however, will compound very well with gum chicle and may be used as an extender. These are derived from the low-grade rubber of Borneo, known as pontianak or jelutong, and the inferior guttas, such as gutta siak. Waxes, resins, and balsams may also be substituted for the gum chicle. A standard formula²² is as follows: chicle, 14%; chicle substitute, 14%; dextrose, 14%; caramel paste, 1%; powdered sugar (XXXX), 57%; plus flavor as required.

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Chapter XIX

FRUIT JUICES, JAMS, JELLIES, AND PRESERVES

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I. FRUIT JUICES

Fruit juices were prepared for use in a fresh state long before the discovery of preservation by heat in hermetically sealed containers, and were among the first foods preserved in this manner by Nicolas Appert, as early as 1810. In spite of this early beginning, it was not until 120 years later, or about 1930, that canned fruit juice began to assume its present important position in the nation's food habits.¹

Welch has been credited with starting the canned fruit juice industry in America in 1869, when he began bottling unfermented grape juice. This product developed slowly and was the only juice canned commercially in important quantities until about 1925. During the period from 1925 to 1930, tomato and grapefruit juices were introduced commercially.

1. Production Data

The production of canned fruit juice has increased during the past 12 years until the total volume packed now approaches that of canned fruits. Over 61,000,000 cases of fruit juice were canned in 1941, compared with a pack of over 91,000,000 cases of canned fruit including tomatoes. Table 53 shows the increase in production of some of the more important canned fruit juices and the total annual pack of all fruit juices since 1929.

Florida and Texas are the principal producers of grapefruit juice. In addition to grapefruit juice Florida canned over 2,500,000 cases of blended orange and grapefruit juice in 1941. Most of the grape juice is packed in New York, though Washington, Arkansas, and Ohio also produce considerable quantities. Orange juice is packed chiefly in Florida and California, and pineapple juice is canned in the Territory of Hawaii. Tomato juice is produced over a wide area of the United States. Indiana, California, New York, Pennsylvania, New Jersey, and Illinois can large quantities

¹ The term "canned" is employed in this chapter in the sense commonly applied by the food industry, *i. e.*, to include food preserved in hermetically sealed tin or glass containers.

of this juice. California packed about 300,000 cases of lemon juice in 1941. About 500,000 cases of apple juice were packed in 1940. Michigan, New York, and the Pacific Coast States are the principal source of this juice. The remainder of the total canned fruit juice pack consists of berry juices, miscellaneous citrus juices and concentrates, and fruit juice beverages such as fruit nectars and prune juice prepared from dried prunes.

TABLE 53

UNITED STATES PRODUCTION OF CANNED FRUIT JUICES (IN ACTUAL CASES OF ALL SIZES)^a

Year	Grapefruit juice	Grape juice	Orange juice	Pineapple juice	Tomato juice	Total, all fruit juices
1929	205,000	.....	.....	.....	185,000	390,000
1930	115,708	.....	37,552	.....	1,338,964	1,492,224
1931	416,681	.....	99,209	.....	4,583,635	5,099,527
1932	288,324	.....	36,362	.....	4,447,043	4,771,935
1933	738,691	.....	110,597	700,000	4,170,794	5,720,082
1934	739,844	.....	342,678	2,000,000	5,703,920	8,786,442
1935	2,617,155	1,216,810	1,108,199	3,450,000	9,286,590	18,027,971
1936	2,462,902	1,500,000	1,227,186	7,770,000	13,104,809	26,873,261
1937	6,399,078	1,669,419	1,646,059	9,460,000	13,444,972	35,930,908
1938	8,420,833	2,190,000	1,306,183	7,350,000	8,675,403	30,647,133
1939	10,560,630	2,952,477	1,740,841	10,390,000	11,091,068	39,099,300
1940	10,226,942	3,000,000 ^b	3,844,336	11,730,000	12,414,186	44,965,515
1941	16,481,335	3,000,000 ^b	4,286,921	12,500,000	19,046,257	61,364,868

^a From data published in the *Western Canner & Packer*, Yearbook and Statistical Number, 1942.

^b Preliminary figures.

In addition to canned fruit juice, large quantities of unpasteurized fruit juices are produced. The annual production of cider, a term usually reserved for unpasteurized apple juice, has varied from 7,500,000 to 16,000,000 gal. during the period from 1929 to 1939. This product is manufactured and distributed seasonally on local markets and is frequently preserved by means of sodium benzoate. In 1939 nearly 5,000,000 gal. of fruit juice, chiefly grape and citrus, were packed in bulk for export, manufacturing and institutional use. An additional pack of grape juice and pulp and citrus juices are preserved by freezing.

2. Definition

The term "fruit juice" as it developed from early times has meant the clear, or nearly clear, unfermented liquid which separates from sound, ripe fruit on pressing. The juice in many cases is subjected to filtration to remove any insoluble matter which may be carried in suspension. The fresh apple cider and bottled grape juice industries are based on this type of juice. Fruit juice, as known to the modern fruit juice canning industry, has come to include products which consist of the liquid portions of the fruit and considerable quantities of finely divided suspended fruit solids which are incorporated into the juice at the time of preparation. By far the greatest portion of the juice now canned is of this latter type. Federal Food and Drug Adminis-

tration standards for fruit juices, under the Food, Drug, and Cosmetic Act of 1938, have not yet been established except for tomato juice. Old standards under the Act of 1906 are still considered as advisory. United States standards for grades of a number of canned fruit juices have been established by the Food Distribution Administration.

3. Composition

Table 54 shows the proximate composition of some common fruit juices.

TABLE 54
PROXIMATE COMPOSITION OF AMERICAN FRUIT JUICES^a

Juice	Water, %	Protein, %	Fat, %	Ash, %	Sugars, %	Acid, % ^c
Apple	87.1	0.1	0.0	0.25	10.5	0.52 ^m
Blackberry	91.4	0.3	0.0	0.39	6.0	1.13 ^c
Blueberry	85.9	0.1	0.0	0.19	12.4	0.19 ^c
Cherry ^b	87.7	0.5	0.6	0.3	9.1	..
Currant (red)	89.1	0.3	0.0	0.54	6.2	2.00 ^c
Grapefruit (unsweetened)	88.0	0.4	0.1	0.4	8.5	1.6 ^c
Grape (bottled)	81.0	0.4	0.0	0.4	16.8	0.8 ^m
Lemon	91.0	0.4	0.3	0.3	2.0	5.0 ^c
Lime	91.0	0.4	0.0	0.3	1.4	6.9 ^c
Loganberry	88.9	0.6	0.0	0.40	6.5	1.89 ^c
Orange	86.0	0.6	0.1	0.4	9.0	1.0 ^c
Pineapple	86.2	0.3	0.1	0.4	12.0	1.0 ^c
Prune	80.0	0.4	0.0	0.3	13.0	0.2 ^c
Raspberry (red)	90.8	0.4	0.0	0.46	7.3	1.40 ^c
Strawberry	94.2	0.2	0.0	0.45	3.63 ^d	1.01 ^c
Tomato (0.5% salt added)	93.5	1.0	0.2	1.0	3.4	0.4 ^c

^a Values taken from U. S. Dept. Agr., *Circ.* 549 (June, 1940).

^b Data from Harry W. von Loesecke, *Outlines of Food Technology*. Reinhold, New York, 1942.

^c Superior letters ^c and ^m represent citric acid and malic acid, respectively.

^d The value given for fresh strawberries is 5.3, indicating some loss of sugar in the juice samples reported, possibly due to fermentation.

Table 55 shows the amount of suspended insoluble solids in a number of cloudy fruit juices.

TABLE 55^a
SUSPENDED INSOLUBLE SOLIDS IN CLOUDY FRUIT JUICES

Juice	Volume of suspended solids, % ^b
Tomato	24 -33
Orange	7 -13.5
Pineapple	13 -17
Apple (pulpy)	15 -18
Grapefruit	3.5-11

^a R. H. Lueck and R. W. Pilcher, *Ind. Eng. Chem.*, 33, 292 (1941).

^b Determined by centrifuging a 50-cc. sample 10 min. at 1313-1320 r. p. m. in a 15-in. diameter centrifuge.

In addition to the readily available source of energy in the form of sugar, certain fruit juices are good sources of vitamin C. Also highly important from the consumer point of view is the appetizing and refreshing flavor of fruit juices. The recent great increase in the consumption of canned fruit juices can be attributed in part to the development of methods of manufacture and preservation which retain these qualities.

4. General Methods of Manufacture

A. PREPARATION OF JUICE

(a) Selection of Fruit

The fruit-juice industry originated in many cases through a desire to utilize fruit cannery by-products, surplus fruit, or fruit which was unsuited for the fancy fresh-fruit market because of shape, size, color, or blemishes. The rapidly growing demand for fruit juice has in many cases resulted in the use of fruit far in excess of the quantities available in these classes, and additional crops are planted to meet this demand.

Some varieties of fruit are more suitable for juice than others. The varieties used should have a rather pronounced and characteristic flavor, aroma, and color, and juices prepared from them should retain these qualities during processing and storage. They should possess a palatable balance between acidity and sugar. Often these characteristics can best be achieved by blending the juice of two or more varieties.

(b) Maturity of Fruit

Properly matured fruit only should be used for juice purposes. Immature fruit, fruit past prime maturity, or fruit containing spoilage readily reflects such a condition in juice prepared from it, lowering the quality of the product. In certain fruits such as tomatoes and pineapple, the period of optimum maturity is relatively short, requiring rapid handling from the time of harvest to the canning operation. In other fruits such as apples, the fruit may retain good quality for 2 or 3 months with suitable storage. The importance of proper maturity of fruit in making high-quality juice cannot be overemphasized.

(c) Preparation of Fruit

Washing and sorting of fruit are necessary in the production of fruit juice so that dirt and spoiled fruit are completely removed. Fruit carrying spray residues must be cleaned with suitable wash solutions when necessary to reduce such residues below federal tolerances in the resulting juice. Washing is often accomplished by use of machines designed for washing the fruit for fresh market or canning and special types of washers have been developed for different fruits. These types include soaking and agitating tanks for fruits such as the tomato which may be contaminated with soil. To avoid bruising, soft fruits such as berries are rinsed with water while passing along on a woven wire belt. After washing, excess water is removed and the fruits are sorted to remove any spoiled or otherwise undesirable fruit.

(d) *Extraction of Juice*

Recent developments in equipment designed to meet the specific requirements of different types of fruit for the production of high-quality juice have undoubtedly contributed in a large measure to the rapid expansion of the fruit-juice industry. Because of the corrosive action of fruit acids on metals, all metal parts of equipment

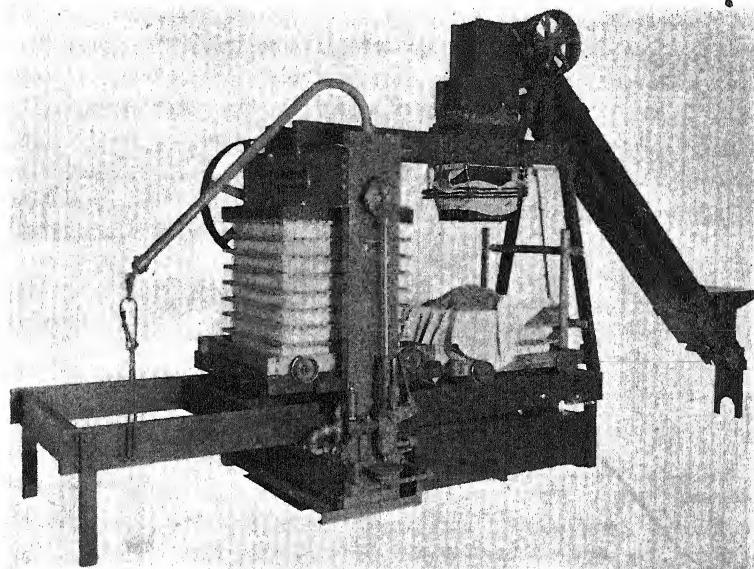


Fig. 139a.—Hydraulic press for fruits.²

which come into contact with fruit juice should be made of acid-resistant metal not only to prevent deterioration of the equipment, but to avoid the deleterious effects of certain metals, such as copper and iron, on the juice. Stainless steel, monel metal, or other special acid-resistant alloys, aluminum, or glass-lined equipment are preferred. The equipment is so arranged that the product can be handled very rapidly after the fruit is crushed to prevent the deleterious action of enzymes, oxygen, and microorganisms. Modern designs avoid as far as possible the incorporation of oxygen into the juice during its manufacture.

Probably the oldest method of extracting juice consists in subjecting the crushed fruit to pressure in such a manner that the fruit flesh remains behind in the press and the juice flows free. The fruit may be crushed by either grater or hammer mills which reduce the fruit to a coarse pulp from which the juice may be pressed readily.

² D. K. Tressler, M. A. Joslyn, and G. L. Marsh, *Fruit and Vegetable Juices*. Avi, New York, 1939, p. 52.

Certain fruits such as grapes yield juices of improved quality if they are heated before pressing. Racks and cloths are most commonly used to hold the crushed fruit during the pressing operation. The crushed fruit is wrapped in a heavy, coarsely woven press cloth to form a cheese. Several cheeses are placed in a tier with wooden racks between them. Pressure is commonly applied by a hydraulic press. Fig. 139a illustrates this type of fruit juice extractor. Basket presses and bag presses operating on the same principle are also used. All such juice extractors are intermittent rather than continuous in operation and employ two distinct steps, crushing or heating, followed by pressing. They require considerable hand labor in preparing the cheeses and in removing the pressed pomace. They are commonly used in the preparation of apple and grape juice and yield products relatively free from insoluble suspended matter.

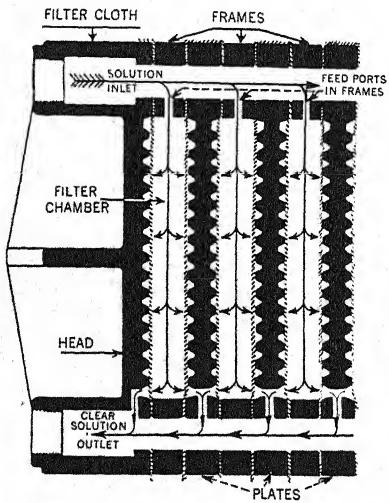
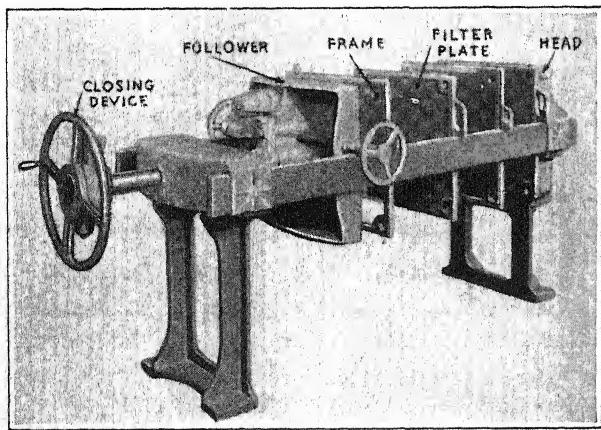


Fig. 139b.—Essential features of the filter press and assembly (see page 598).³

A somewhat different product results from the utilization of a more recently developed type of press which is continuous in operation. In this type, a combined crushing and pressing action forces the fruit into contact with screens under comparatively gentle pressure. Such action tends to grind the fruit and force the softer insoluble cellular matter through the screens as well as press out the liquid portion of the fruit, separating it from skins, seeds, and coarse fibrous flesh. The propelling and squeezing forces may be applied by conical screws which revolve within a perforated cylinder or by paddles or brushes revolving within cylindrical screens. A variety of such extractors have been developed to meet the requirements of different fruits. The most desirable machines, on the basis of flavor, color, and vitamin retention in the

³ Univ. of Calif., "Commercial Production of Fruit Juices," *Circ.* 344, 29 (Nov., 1937).

juice, are those which reduce to a minimum the contact of juice with air. This type press is not well adapted for extracting juice from firm-fleshed fruit unless a preliminary grinding or heating is made. The amount of insoluble solids forced into the juice can be controlled in most cases by adjustments on the machines. Tomato juice is commonly prepared in a press such as shown in Fig. 13, Chapter V, page 178.

Another recently developed method for the extraction of juice from fruit having a firm texture consists in passing the fruit through disintegrating or comminuting machines which reduce it to a very fine pulp before pressing. The finer pulp particles pass into the juice during the pressing operation which is usually accomplished by means of continuous screen presses. Juice high in suspended solids results from this process. This method is used very successfully in preparing pineapple juice.

A specialized type of equipment is required for extracting citrus juices in order to avoid the inclusion in the juice of peel oils which give an undesired flavor. The most satisfactory equipment involves the reaming principle commonly used in the home for preparing the same juices.

After extraction, fruit juice is strained or screened when necessary to remove seeds and other objectionable solids which may be present. Screens are preferably of the self-cleaning type such as rotating, inclined cylindrical screens, or vibrating screens.

(e) *Blending of Juice*

In order to prepare a product fairly uniform in composition and flavor, blending of juice is frequently practiced. Juice from different varieties, lots, or fractions obtained during the pressing operation may be blended to control the acid, soluble solids, and suspended solids content of the finished juice. Total acidity, as determined by titration of the filtered juice, is most frequently used in determining the acidity of juice. Soluble solids may be checked by means of a hydrometer. Suspended solids, as volume per cent, may be determined by centrifuging the juice in calibrated tubes. Blending is accomplished in tanks supplied with agitators into which juices from various lots are pumped until the resulting juice meets the required standard.

(f) *Control of Suspended Solids*

Fruit juice as it flows from the blending tank contains varying amounts of suspended solids depending upon its method of preparation. If desired, the juice is submitted to some treatment either to regulate the amount of suspended matter present in the finished juice or to remove it completely. The amount of suspended solids may be regulated to a predetermined level either by use of screens or by centrifuging. Both methods can be made continuous in operation. When bulk storage before packaging for distribution is practiced, suspended solids have sufficient time to settle by gravity and can then be removed.

Filtration.—Although many fruit juices are more popular when they contain suspended solids, consumer acceptance of certain juices is increased by clarification. Filtration is generally used when a clear juice is desired. A number of compact filters offering a large filtration surface have been developed for this purpose. In general,

they consist of a support for the filtering surface, a device for forcing the juice through this surface, usually under pressure, and subsequent removal of the filtered juice. (See Fig. 139b). The type of filtering surface used depends somewhat on the juice to be filtered and the degree of clarity desired. Canvas or metal cloth which has been coated with diatomaceous earth, asbestos fiber, or paper pulp may be used. These filtering substances are suspended in water which is then passed through the cloth until a coating has been deposited. This coat serves to decrease the pore size of the cloth, thus causing the filter to remove the more finely divided matter. Prepared filter sheets made of paper and asbestos pulp and tubes of porous porcelain are also used as filtering surfaces.

Most fruit juices contain mucilaginous hydrophilic material in conjunction with the suspended solids which tend to clog the filter, making direct filtration difficult, and a very retentive filter is required if a clear juice is to result. In order to remove these substances or reduce their tendency to clog the filter, some special treatment is usually given to the juice. Diatomaceous earth, suspended in the juice, aids in filtration by forming a porous cake on the filtering surface. One of the most effective treatments to improve filtration consists in the use of pectin-decomposing enzymes. Fining of the juice by means of gelatin, gelatin and tannin, or bentonite is also employed; see page 28. These agents cause the insoluble matter to settle and the relatively clear supernatant juice is readily filtered to remove last traces of insoluble solids. Centrifuging, coagulation by heat, or a combination of these may also be employed to aid filtration. In some untreated juice, a series of filtrations is necessary, each through successively more retentive filters, before a clear juice can be obtained.

Homogenization.—From the standpoint of appearance, one of the undesirable features of juice containing suspended solids is the tendency of the solids to settle during storage. This is particularly noticeable in juice packed in glass but may not be evident to the consumer when juice is packed in cans since the can usually receives sufficient agitation immediately before use to resuspend the solids. Separation of solids may be retarded by homogenization.⁴ This process consists in forcing the juice under high pressure through small openings, thus reducing the size of the suspended particles. Machines similar to those used for homogenizing milk and other food products are employed sometimes to retard settling, particularly when juice is packed in glass.

(g) Deaeration

Fruit juices generally retain their fresh flavor and aroma more completely when prepared and packaged in the absence of oxygen. This is particularly so in the case of citrus juices. Vitamin C is unstable in the presence of oxygen. Some juice-pressing machines are designed to operate in an inert atmosphere, thus avoiding contact with oxygen from the air. However, most fruits contain oxygen and other gases in their intercellular spaces, a part of which is dissolved and occluded in the juice. Removal of oxygen from juice may be accomplished either by subjecting the juice to

⁴ H. J. Loeffler, *Proc. Inst. Food Tech.*, 1941, p. 29.

a high vacuum while it flows over baffles in thin films or by spraying it into an evacuated chamber. This process is commonly known as deaeration and several efficient types of deaerators are now in use. The benefits of deaeration are largely lost if contact with oxygen is not avoided during the process of pasteurizing and sealing the juice in containers. Special filling and sealing devices have been recommended, since the amount of air trapped in the head space of the container during the usual operations is greater than that which can be removed by deaeration.⁵

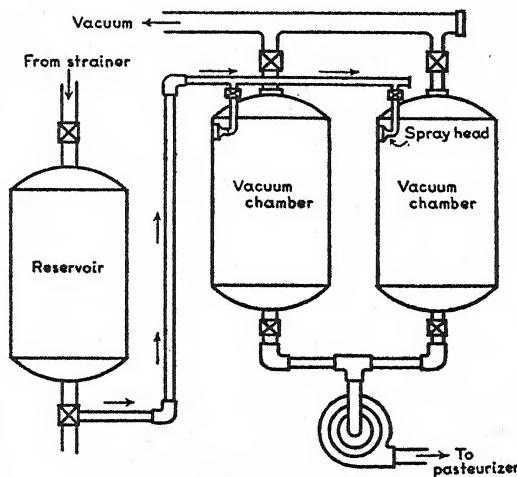


Fig. 140a.—Diagrammatic representation of a deaerating unit.

(h) Carbonation

Although satisfactory carbonated juices may be made from apple, cherry, loganberry, and other fruits, consumer acceptance of these products has not been so widespread as for other carbonated beverages. Certain carbonated beverages, such as orangeade and limeade, contain fruit juice added in the form of fruit sirup. The minimum percentage of various fruit juices required to give a readily recognizable flavor in the finished beverage varies from 6% for fruits such as raspberry to as high as 21% for grape beverages.⁶ Certain States specify by law the minimum amounts of fruit juice required in some carbonated beverages.

Carbonation of pure fruit juices may be achieved by commercial equipment used for the carbonation of water for beverage purposes provided corrosion-resistant metals have been used in those parts which come in contact with the juice. Low-

⁵ R. H. Lueck and R. W. Pilcher, *Ind. Eng. Chem.*, 33, 292 (1941).

⁶ J. H. Irish, *Fruit Products J.*, 12, 196 (1933).

pressure carbonation is preferred for juices of moderate or low acidity to avoid masking the fruit flavor. See pages 715 *et seq.*

B. PRESERVATION OF JUICES

(a) *Preservation by Heat*

Fruit juice not intended for immediate consumption must be subjected to some preservation process to prevent spoilage. The most important commercial method of preservation is pasteurization. This depends on the destruction by heat of those microorganisms capable of growth in juice packed in hermetically sealed containers. Usually freshly pressed fruit juices have the most desirable flavor and aroma. To retain this fresh quality, particularly in heat-sensitive juices, heating may be limited to that necessary to destroy yeast. Bacteria surviving such treatment are not capable of multiplying in a medium as acid as fruit juice, and mold growth is prevented by the elimination of oxygen from the container. The temperature should be sufficiently high to inactivate enzymes capable of causing deterioration in the quality of the juice during storage.

The thermal destruction of microorganisms is a function of both time and temperature. For example, it has been shown that certain fruit juices can be preserved successfully by heating to a temperature of 135° F. for several hours; to 150° F. for 30 min.; or to 170° F. for 1 min.⁷ The minimum safe time and temperature required to preserve a given juice vary with acidity, heat conductivity, and initial contamination.

Two methods of pasteurization have come into use. Either method, when properly conducted, is successful in retaining the natural fresh flavor of juice. The older method, now termed holding pasteurization, depends on the use of a relatively low temperature maintained over an extended period. The containers are filled either with cold juice or juice at a temperature near the one to be used in pasteurizing and sealed. The containers are then brought to the pasteurizing temperature by means of a water bath or spray and held there until pasteurization is complete. The containers should be cooled rapidly. In large commercial operations, this method requires rather elaborate equipment for holding the juice at the desired temperature.

A more recent method, flash pasteurization, depends on the use of a temperature sufficiently high to accomplish preservation in a relatively short time. The juice is heated to the required temperature in a few seconds as it passes through tubes or between plates. Heat is applied either by steam or a steam-heated water bath. Several types of flash pasteurizers are in use and automatic equipment to control juice temperature has been developed. The hot juice may be cooled partially before filling, or filled directly into containers, which are then sealed and inverted so the hot juice will sterilize the lid. They are then rapidly cooled in water. The entire period during which the juice remains hot is generally limited to 1 to 3 min. Temperatures commonly employed vary from 170 to 190° F. depending on the juice being processed. Flash pasteurization is rapid and equipment costs are low, but accurate tem-

⁷ C. S. Pederson and E. A. Beavens, *Food Industries*, 12, No. 4, 61 (1940).

perature control is required. A modification of flash pasteurization occasionally used consists in vacuum sealing juice in cans while cold, and rapidly spinning the cans

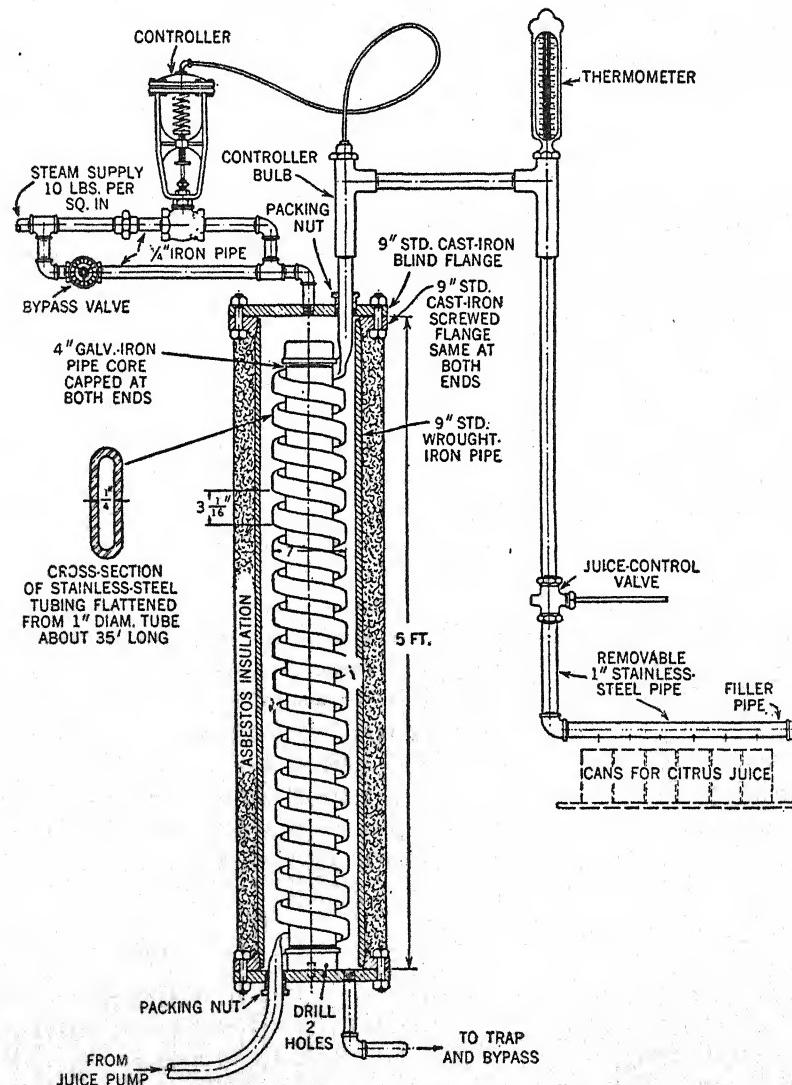


Fig. 140b.—Commercial flash pasteurizer.^{7a}

in a spray of hot water or steam, followed by a cold water spray after the pasteurization temperature has been attained.

^{7a} U. S. Dept. Agr., "Citrus Fruits Products," *Circ. 577*, 11 (Nov., 1940).

Filling and sealing the container are integral parts of the heat-preservation process since the container must be sterilized and sealed to ensure preservation of the juice. Many types of fillers have been developed, the simplest of which consists in passing the containers under a spout or perforated pipe from which the juice flows. When the container is filled at the pasteurization temperature, a partial vacuum results due to the contraction of the juice during cooling. When containers are filled and sealed cold or at a lower temperature than that attained in pasteurization, sufficient head space must be left in the container to allow for the expansion of the juice by heating. A satisfactory method of removing oxygen from the head space and ensuring a vacuum in cold-filled juice is to fill the head space with live steam during the sealing operation. Steam or an inert gas may also be used to remove oxygen from the head space of hot-filled containers. After pasteurization, the container should be cooled rapidly to avoid the development of cooked flavor.

(b) *Preservation by Freezing*

Probably the most satisfactory method of preserving the fresh fruit flavor of many of the fruit juices is by freezing. Juice preserved in this manner need not receive any heat treatment, and flavor changes which occur in storage at ordinary temperatures are retarded. The pack of fruit juice preserved by freezing is, however, limited because of the expense and problems connected with distribution. The juice must be held at from 0 to 15° F. until thawed for use because microorganisms present in the juice are not destroyed by freezing. The process is now used principally for holding juice for later processing, although small quantities of citrus and apple juice are preserved in this way for fountain distribution. Deaeration has been found desirable for some juices preserved by freezing. To retain its fresh flavor, the juice should be frozen as soon after preparation as possible. The cooled juice may be packed in tin cans, waterproof fiber containers, or in bulk, and rapidly frozen, or it may be frozen to a slush in a continuous freezer before packaging. Containers should be filled to only nine-tenths their capacity with unfrozen juice to allow for expansion during freezing.

(c) *Preservation by Chemicals*

Chemicals used in preservation are confined principally to benzoic and sulfurous acids or their salts and their presence can usually be detected by the flavor they impart to the juice. Sodium benzoate is used principally to increase the shelf life of unpasteurized apple juice. It is effective in preventing spoilage when present in concentrations of from 0.1 to 0.3%, the quantity necessary varying with the acidity of the juice.⁸ The salt is dissolved in water and added to the juice at the time of preparation. Sulfurous acid is used mainly for preserving juice in bulk for export or for manufacturing purposes. Concentrations necessary to prevent spoilage vary from

⁸ W. V. Cruess, P. H. Richert, and J. H. Irish, *Hilgardia*, 6, 195 (1931).

0.02 to 0.1%, as sulfur dioxide, depending on the juice preserved. Sulfur dioxide has the undesirable property of bleaching the juice. It is added in the form of sulfurous acid salts or as gas from a cylinder. The Federal Government and many States require a declaration on the label of the presence of such added chemical preservatives.

(d) *Sterilization by Filtration*

Another method of preservation which is used more extensively in Europe than America is sterilization by filtration. This method obviously can be used only for juices to be marketed in a clear condition, and clarification must precede filtration for sterilization. The method depends on passing the juice through filters capable of removing microorganisms and offers the advantage that the juice need not be heated. The process must be carried out in sterile equipment and the juice sealed in sterile containers under aseptic conditions. Because of the danger of contamination in packaging, juice preserved in this manner is generally packed in glass so that occasional spoilage by molds can be detected before the juice reaches the consumer.

(e) *Other Methods of Preservation*

Juice is also preserved in bulk by the Bohi⁹ process which depends on the preserving action of carbon dioxide applied to juice at 120 lbs. per sq. in. pressure at 60° F. or lower. Juices may also be preserved for a short time by storage at a temperature just above their freezing points. Contact with oxygen should be avoided to prevent mold growth. A number of other methods of preservation have been developed but their commercial use is as yet limited. Among these are the Katadyn⁹ and the Matzka⁹ processes which depend on the oligodynamic properties of silver.

C. PACKAGING AND STORAGE OF JUICE

(a) *Containers*

Both tin-plated cans and glass bottles are used as containers for fruit juice. Specially lacquered or enameled tin plate is recommended to preserve the flavor and color of some juices, such as grape, orange, and apple, and to prevent excessive can corrosion. Others may be kept satisfactorily in plain tin plate. Bottles were used almost exclusively by the early canned fruit juice industry because suitable tinned containers were not then available. The use of tin or glass containers for juice is now determined largely by economic factors. The rapid advance in fruit-juice production was attained largely by juice packed in cans. However, the curtailment in the use of tin because of the war emergency and improvements in glass containers and methods for handling them has developed a tendency toward the greater utilization of glass. The ability of the glass industry to meet the present emergency and to compete with tin plate available in the future will determine the permanency of this trend.

⁹ V. L. S. Charley and T. H. J. Harrison, *Fruit Juices and Related Products*. Imperial Bureau of Horticultural and Plantation Crops, East Malling, Kent, England, 1939.

(b) Storage of Preserved Juice

Pasteurized fruit juices, although stable to decomposition by organisms, undergo flavor changes during storage. While many fruit juices will retain their fresh flavor for months at ordinary storage temperatures this quality depreciates quite rapidly in juices such as orange and lemon. Chemical changes attending this loss in flavor are complex and not well understood but proceed much more rapidly at higher temperatures. For this reason fruit juices should be stored at a cool temperature.

5. Manufacture of Different Fruit Juices

(a) Apple Juice

Although all apple varieties grown commercially are used for juice, Baldwin, Delicious, Northern Spy, Greening, McIntosh, Jonathan, and Winesap are the most popular. Juices are generally prepared from blends of two or more varieties. In order to attain the best flavor, juice with an acidity of 0.4% or higher, and a Brix of at least 12.5° is considered most desirable.¹⁰ Particular care must be exercised in selecting fruit properly matured and free from spoilage because of the easily masked, mild flavor of apple juice. Nearly all apple juice is prepared by crushing the apples in a hammer or grater mill and pressing by means of rack and cloth presses. Yields vary from 150 to 180 gal. per ton. The juice obtained from the press is cloudy but contains a relatively low quantity of suspended solids.

Besides the conventional pressed apple juice, a small pack of canned pulpy apple juice, containing considerable quantities of suspended solids, is prepared by use of comminution machines. Such juice is marketed cloudy and differs from other apple juice in both flavor and appearance.

The canned apple juice industry is in a state of flux, and commercial juice is prepared for canning in a wide variety of ways. Although the greatest quantity of apple juice is probably consumed as it flows from the press, with or without preservation by sodium benzoate, canned apple juice is more popular when clarified.¹⁰ Clarification is usually accomplished by means of pectin-decomposing enzymes or by direct filtration. However, most of the methods previously described to achieve clarification are in use. There is a limited use of deaeration. Both flash pasteurization and holding pasteurization are employed. Fresh apple flavor is sensitive to heat, and precautions to limit the heating process to a safe minimum are necessary to avoid obtaining a cooked flavor. Preservation by sterile filtration and by the Bohi process are methods used principally in Europe. A small quantity of juice is preserved by freezing. Enamelled tin and glass containers are most commonly used, although some juice is packed in plain tin.

(b) Pineapple Juice

This product was originally prepared from juice drained from the fruit during canning but its rapid increase in popularity has resulted in the use of a large amount

¹⁰ H. H. Mottern, Truman Nold, and J. S. Hudnut, U. S. Dept. Agr., Bur. Agr. Chem. Eng., Mimeo graph A C E-186 (1942).

of whole pineapple for juice. Commercial pineapple juice contains about 15% suspended solids. Pineapple fruit is prepared for juice extraction by methods similar to those used in preparing the fruit for canning. In addition to this fruit, shreadings, cores, and broken slices and excess juice from crushed pineapple, obtained in preparing the fruit for canning, are used for juice. The prepared fruit is passed through a comminuting or disintegrating machine where it is pulped before pressing. Either hot or cold methods of extraction are employed, depending on the individual packer. The general procedure followed in both methods consists of a combination of screening and pressing operations which press the liquid from the pulp and permit the more finely divided flesh to pass into the juice. Several fractions of juice are obtained in these pressing operations. By blending these fractions a juice of the desired sugar, acid, and suspended solids content is obtained. The juice may be finished by means of a paddle type finisher or a centrifuge which finally establishes the amount of suspended solids. Both flash and holding pasteurizations are used for preservation. The heat treatment is kept to a safe minimum since the flavor of the juice is quite sensitive to heat. Plain tin cans are used exclusively. Yields average about 35 cases of 24 No. 2 cans per ton of fruit.

(c) *Citrus Juices*

Grapefruit juice, which constitutes the largest pack of the citrus juices, is manufactured chiefly from the Duncan and Marsh Seedless varieties. Orange juice prepared from the Temple, Pineapple, Seedling, and Valencia varieties is most satisfactory. The Eureka and Lisbon varieties of lemons are the main source for juice. A small pack of lime juice is also marketed.

One of the chief problems in preparing citrus juices is the removal of the juice without including oil and juice from the peel which contribute a bitter flavor. For this reason, reaming of the halved fruit is the most satisfactory method of extraction. This is accomplished by procedures varying from hand reaming to the use of automatic machines which handle up to 300 fruits per minute. The amount of suspended solids, which markedly affects the flavor of the juice, can be controlled by the pressure applied to the fruit during this operation. A method has also been developed for pressing juice from oranges after the peel has been removed. Grapefruit yields from 90 to 120 gal. of juice per ton of fruit, oranges from 75 to 110 gal., and lemons from 70 to 80 gal.

The juice flows from the reamers to screening equipment where seeds and undesired suspended solids are removed. Deaeration has been found important in the preservation of orange and lemon juices and of value in canning grapefruit juice not only to aid in vitamin C retention but to retard certain flavor changes caused in the juice by oxygen. It is therefore important to handle these juices as rapidly as possible before deaeration and to avoid reoxygenation during the pasteurizing and filling operations. Head space in the container should be held to a minimum or the air replaced with an inert gas. Flash pasteurization or vacuum closure of the cold juice followed

by a hot-water process of the rapidly rotating cans and rapid cooling are the most common methods of preservation. Grapefruit juice is commonly packed in plain tin cans while enameled cans are preferred for orange juice. Lemon juice is packed in both plain and enameled cans. A considerable volume of blended orange-grapefruit juice containing from 35 to 45% orange juice is packed.

Storage below 60° F. and rapid merchandising are desirable to prevent the development of off-flavors during storage and to reduce can corrosion. The development of off-flavors during storage of canned citrus juices, particularly orange and lemon juice, has been a serious handicap to the production of these juices and is the subject of considerable research. It is believed that off-flavors in Florida Valencia orange juice are due in part to oxidative changes of the fat.¹¹ The tendency to develop off-flavor during storage appears to be less pronounced in juice prepared from fully mature fruit. Darkening of packaged orange juice during storage has been found to be influenced by heat, especially in the presence of oxygen, and to be associated with the oxidation of ascorbic acid.

A considerable volume of orange, and also lemon juice, is packed frozen for fountain distribution. The juice should be frozen as rapidly as possible to obtain a product which is uniform throughout the container. Some grapefruit juice, preserved with sulfur dioxide, is packed in barrels for export. An important supplementary industry has been developed based on the concentration of citrus juices for use in soda fountain beverages.

(d) *Grape Juice*

The Labrusca varieties, of which Concord is the most common, are used almost exclusively for the commercial preparation of grape juice. A limited quantity of juice is prepared from Muscat and blends of Muscat with other European varieties. The proper maturity of the fruit is frequently checked before harvest by measurement of the soluble solids of the juice, using a hydrometer or refractometer. After washing, and removal of excess water, the fruit is passed through a specially designed stemmer which, by a beating action, removes the stems and partially crushes the grapes. Stems, if heated with the fruit, impart a bitter, astringent taste to the juice. The fruit is then transferred to steam-jacketed kettles or continuous tubular heaters where it is heated to a temperature of 135 to 160° F. The color is extracted from the skin of the grapes by heating, and regulation of temperature is used to control this quality in the juice. Rack and cloth type presses are employed to extract the juice of Labrusca varieties. Screw presses may be used for European varieties. From $\frac{1}{2}$ to $2\frac{1}{2}\%$ diatomaceous earth is generally added to the pulp as an aid in pressing and to increase the yield. The fruit yields about 180 gal. of juice per ton.

Grape juice, as it flows from the press, is a supersaturated solution with respect to potassium hydrogen tartrate and possesses a harsh acid flavor. The excess tartrate (argols) precipitates during storage. Although a limited amount of juice is packed

¹¹ Arthur J. Nolte, George N. Pulley, and Harry W. von Loesecke, *Food Research*, 7, 236 (1941).

directly after straining or centrifuging, the preferred practice is to remove the tartrate by storage in bulk before packaging for distribution. This avoids the presence of a precipitate in the marketed juice. A partial clarification is also attained during storage as a result of the settling of suspended solids. It is possible to remove the excess tartrate within 24 hrs. by rapid freezing, thawing, and filtering. Detartration by bulk storage is accomplished in one of two ways. The juice may be flash-pasteurized, rapidly cooled to about 28° F., and stored at this temperature in sealed cement, wooden, or metal tanks which have been treated with a protective coating. This low temperature inhibits the growth of microorganisms and causes a relatively rapid precipitation of the tartrate. In the alternate method the juice is heated to a temperature of 170 to 190° F., filled hot into glass carboys or stoneware jugs, sealed with corks, cooled, and stored until the excess tartrate precipitates. Care must be used in heating and sealing to assure preservation as storage temperatures are usually not sufficiently low to prevent spoilage. Open kettles are preferred by some to heat the juice so that difficultly sterilized pulp may be skimmed off. The storage temperature used depends upon the rate and extent of tartrate precipitation desired and upon the juice itself. In some seasons juice prepared from the Concord variety grown in some sections of the Pacific Northwest is so low in acid and high in sugar that continued storage at 40° F. could result in an insipid juice. The juice is usually held in bulk storage until required for marketing.

The juice is siphoned off before bottling and the tartrate, a valuable by-product, is recovered. The juice may be filtered to increase its clarity. Enzyme treatment to decompose pectin has been proposed to improve the filtering properties. Deaeration is not commonly practiced. Grape juice is commonly packed in bottles although special enameled cans have recently come into use. The juice is generally preserved by holding pasteurization.

From the foregoing description it may be seen that grape juice of highly satisfactory quality may be prepared without the rather elaborate precautions with regard to speed of handling or minimum heat treatment required for many other juices. This accounts in part for its early development as a preserved fresh juice.

(e) Tomato Juice

Varieties commonly grown for canning such as Stone, Marglobe, Norton, John Baer, and Bonney Best are used in preparing juice. A small pack is prepared using yellow varieties. Firm, fully colored fruit is necessary for a good quality juice. The fruit is thoroughly washed and carefully sorted and trimmed to remove surface dirt, mold growth, and insect-infested portions. The core of the fruit has an objectionable flavor and is usually removed. It is necessary to use care in these preparation steps not only to ensure a good flavor but to obtain a product which will comply with federal tolerances for mold and insect fragments.

The prepared fruit may be extracted by either the hot- or cold-break method, depending upon the product desired. The hot-break method, in which the fruit is heated

to a temperature of about 165° F., yields a juice with a higher viscosity and less tendency to separate the suspended solids. The yields are increased by this method. The increased body is due to the greater extraction of pectin and to inactivation of pectin methoxylase present in the fruit. The fruit is chopped and then heated in continuous tubular heaters or in steam-jacketed kettles supplied with agitators. Federal regulations prohibit heating the fruit by the direct injection of live steam as the condensate serves to dilute the finished juice. In the cold-break process the trimmed fruit is passed directly to the extractors. This process yields a thinner juice and the product has a flavor more nearly resembling fresh tomatoes.

Tomato juice is extracted by means of continuous extractors which force the liquid and soft portions of flesh through fine screens thus removing the seeds, skin, and hard portions of flesh. Extractors which tend to whip air into the juice are undesirable since oxygen not only destroys vitamin C but causes undesirable color and flavor changes. Homogenization is sometimes used to retard separation of suspended solids, particularly if the juice is packed in glass. Deaeration has been recommended but is not commonly employed.

The juice is preheated to 170° F. or above, either in continuous tubular heaters or in kettles, and then is filled into cans or bottles. Salt is usually added at a rate of from 4 to 6 lbs. per 100 gal. The precautions observed with many fruit juices to avoid a cooked flavor are not necessary in the preparation of tomato juice. A raw flavor is considered undesirable by many, and heat treatment must be relatively severe before an undesirable cooked flavor results. The rather low acid content of tomato juice requires a more severe heat treatment to assure preservation. The filled containers are commonly processed by immersion in boiling water, followed by water cooling. Plain tin cans are most frequently used though some juice is packed in enameled cans and in bottles.

(f) Other Juices

Although the foregoing constitute the principal fruit juices on the basis of quantities produced, other juices are prepared commercially. Among these are berry juices, cherry, and plum juice and some tropical fruit juices such as papaya and passion fruit juice. Experimental work has been done on methods of preparing juice from still other fruits.

Space does not permit detailed description of methods of preparation, and processes vary somewhat for each fruit and with different processors. Berry, cherry, and plum juices are usually prepared by heating the fruit to increase the extraction of color and facilitate pressing operations. Rack and cloth, basket, or bag presses are generally used. These juices are commonly filtered and marketed clear. Treatment with pectin-decomposing enzymes may be employed to facilitate filtering, and diatomaceous earth is generally used as a filter aid. The juices may be preserved by either flash or holding pasteurization and are packed in either glass or enameled tin cans.

6. Fruit Beverages, Concentrates, and Sirups

(a) Prune Beverage

A product commonly known in the food industry as prune juice differs from other fruit juices, since it is not the liquid product pressed from fresh fruit but is rather a water extract of dried prunes. It resembles the liquor of home-stewed dried prunes. The annual production of this product is variable but is greater than juice prepared from fresh prunes. Nearly 500,000 cases were packed in 1941, chiefly in California.

This prune product is prepared by one of two methods. The washed, dried prunes may be leached with hot water in a diffusion battery or the fruit may be treated with water at a rate of about 1200 gal. per ton of fruit and the mixture boiled for 60 to 80 min. in a tank supplied with an agitator.¹² The resulting pulp is pressed on a rack and cloth press such as used for cider or grape juice. The juice as obtained by either method may be clarified by filtration or by permitting the suspended solids to settle. The finished product is brought to a soluble solids content corresponding to 19–21° Brix by controlling the extraction process or by concentration either in open kettles or under vacuum. Yields of finished juice vary from 500 to 600 gal. per ton of dried fruit depending upon the process used. Citric acid may be added to increase the tartness. Containers are filled at a temperature above 180° F. and then given an additional cook to assure preservation. The juice is packed in both plain tin cans and glass.

(b) Fruit Nectars

The term nectar is used by industry to designate liquid products of fresh fruits which contain added sugar and water. These beverages, although they resemble fruit juices in flavor, cannot be called fruit juices because of the presence of added water. Nectars vary, as do fruit juices, from clear liquids to products rather high in suspended solids. Certain fruits such as apricots, peaches, pears, plums, and nectarines yield clarified juices which do not have a pronounced flavor. These fruits when pressed by pulping machines yield products of desirable flavor and of puree consistency. In order to obtain a more fluid consistency, a sugar sirup is added. Some fruits such as youngberries and raspberries yield a very tart juice of relatively low sugar content. Such juices can be improved by the addition of a sugar sirup to give a more palatable balance of sugar and acid.

(c) Fruit-Juice Concentrates and Sirups

Although no clear distinction is made between fruit-juice concentrates and sirups, the term "sirup" is generally reserved for products to which a considerable quantity of sugar has been added. The juice in sirups may or may not be concentrated and acid, flavor, and color may be added. Fruit-juice concentrates are in most cases fruit juices which are condensed by the removal of water. These products are used

¹² W. C. Hoffman, *Food Industries*, 11, 432 (1939).

principally in the production of soft drinks and by the baking, jelly, and other manufacturing industries. They may be preserved by means of chemicals, by pasteurization, or by maintaining the concentration of soluble solids sufficiently high to prevent spoilage.

Concentration may be accomplished either by evaporation or freezing. Evaporation must be carried out under a partial vacuum at a temperature not to exceed 150° F. to avoid flavor changes which occur at higher temperatures. Juice when concentrated by this method, loses volatile aromatic principals which contribute to the flavor. This aromatic fraction may be recovered by a fractional condensation of the distillate or by removing the aromatic fraction from the juice before concentration. The latter is accomplished by separately condensing the first fraction of the distillate to leave the juice. This fraction contains a considerable portion of the aromatic principals. Recovery of these aromatic components is unsatisfactory in the case of citrus concentrates. After the concentration process has been completed the recovered aromatic fraction is returned to the concentrate. The final concentrate usually contains about 72% soluble solids as determined by a Brix spindle and each gallon represents the solids from 6 to 7 gal. of fresh juice.

Concentration by freezing is the most satisfactory method for removing water from fruit juice without altering the natural fruit flavors. The process has not been popular commercially because it is more costly than evaporation under vacuum. The juice is frozen to a slush and the ice is removed by means of a centrifuge or filter. This process must be repeated several times in order to achieve a suitable degree of concentration which is usually limited to 50 to 55° Brix by the viscous nature of the concentrate.

II. JELLIES, JAMS, PRESERVES, MARMALADES, AND FRUIT BUTTERS

The preparation of jellies, jams, preserves, marmalades, and fruit butters was developed as an art by the housewife and served as a means of preserving fruit without sealing it hermetically. These products were prepared with a sufficiently high concentration of dissolved solids, because of the addition of sugar and concentration by evaporation, so that fermentation could not occur. Mold growth was usually inhibited by covering the product with paraffin. The popularity of these products increased as sugar became more available. Because of their high sugar content their use as food, however, is limited to that of a delicacy and a dessert. The value of desserts of this type depends upon their desirable flavor, appearance, and consistency. Control of consistency, which depends wholly or in part on the formation of a pectin gel in the presence of the proper concentration of sugar and acid, offered the greatest problem in the preparation of these products. Lack of knowledge of the requirements necessary for pectin gel formation frequently contributed to homemade products of undesirable consistency. The preserving industry awaited the accumulation of sufficient information on the chemistry of pectin and its gels to make control of con-

sistency possible under commercial conditions. As the knowledge of pectin chemistry increased, production grew until it now supplements and to some extent has replaced home-prepared products.

1. Production Data

Table 56 shows the growth in commercial production of jellies, jams, preserves, and marmalades in the United States.

TABLE 56

U. S. PRODUCTION OF JELLIES, JAMS, PRESERVES, AND MARMALADES (IN CASES OF ALL SIZES)*

Year	Cases	Value of pack ^b
1925	7,240,000	\$39,818,707
1927	6,280,000	37,682,393
1929	7,860,000	47,149,358
1931	7,745,000	27,101,113
1933	6,655,000	19,970,362
1935	7,250,000	29,200,597
1937	9,150,000	36,587,742
1939	9,500,000	35,856,725
1940	10,000,000	.....
1941	11,250,000	.....

* *Western Canner & Packer*, Yearbook and Statistical Number, 1942.

^b Includes fruit butters, etc.

In contrast to most fruit-processing industries, the preserving industry is often concentrated in or near population centers rather than at the source of fruit and operates for a much longer season than that in which fresh fruits are available. This is made possible by the use of frozen and canned fruits during seasons when fresh fruits are not available. In England, where preserving is an important industry, fruit is often preserved by means of sulfur dioxide.

2. Definitions

Partly as a result of the manner in which the preserving industry developed, a clear differentiation between these products cannot always be made. Jelly is distinct from the others since it contains little or no insoluble solids. The terms "preserve" and "jam" are generally used synonymously. However, preserves have sometimes been differentiated from jams on the basis of the size of the fruit pieces present, the preserve containing whole fruit or large pieces, whereas jams contain the crushed or disintegrated fruit. Marmalade was originally an English product prepared from bitter varieties of oranges. American marmalades have been variously defined as fruit preserves of pulpy or semisolid consistency, as preserves consisting of slices of a fruit suspended in a jelly, and as a preserve made only from citrus fruits. Confusion in the use of the term "marmalade" could be avoided if it were restricted to preserves made from citrus products since the other definitions apply more nearly to fruit preserves or jams. Fruit butters are the smooth, semisolid product obtained by cooking a screened fruit with either sugar or a fruit juice.

3. Federal Standards

Definitions and standards of identity for various fruit preserves, jellies, and butters, but not for marmalades, have been issued by the Food and Drug Administration under the Food, Drug, and Cosmetic Act of 1938. A brief outline of these standards is presented here.

Jellies are the viscous or semisolid foods made from a mixture of not less than 45 parts by weight of fruit juice ingredient to each 55 parts by weight of saccharin ingredient. The mixture is concentrated by heat to such a point that the soluble solids content of the finished jelly is not less than 65%. Spices, sodium citrate, sodium potassium tartrate, sodium benzoate, benzoic acid, mint flavor, and harmless artificial green coloring may be optional ingredients. Optional saccharine ingredients are corn sugar, invert sugar sirup, sucrose, honey, or combinations of these. Pectin and designated organic acids may be added to compensate for deficiencies of these substances in fruit juice. Inducement for adding pectin or acid in quantities greater than required to supply the natural deficiency of the fruit juice is eliminated by fixing the minimum fruit-juice content. The name of the fruit or fruits present must be indicated on the label as must spices, chemical preservatives, honey, or corn sirup when used.

Standards for jams and preserves are similar to those for jelly except that fruit ingredients are used rather than fruit-juice ingredients and mint flavor and green coloring are not optional ingredients. The fruit mixture is concentrated by heat to such a point that the soluble solids content is not less than 65% for certain specified fruits and not less than 68% for others.

Fruit butters are defined as the smooth, semisolid foods prepared from a mixture composed of not less than 5 parts by weight of one or more fruit ingredients to each 2 parts by weight of saccharine ingredients. The mixture is concentrated by heat to a soluble solids content of not less than 43%. The optional fruit ingredients are: apple, apricot, grape, peach, pear, plum, prune, or quince. Optional saccharine ingredients are sucrose, invert sirup, brown sugar, invert brown sugar, honey, corn sirup, or suitable combinations of these. Spice, flavoring (other than artificial), salt, and designated organic acids are optional ingredients. Fruit juice may be used in a quantity not less than one-half the weight of the fruit ingredient, to replace a part or all of the saccharine ingredients. The name of the fruit or fruits from which the butter is prepared must appear on the label as must spices, fruit juices, added flavor, honey, and corn sirup when used. Dried fruits may be used in whole or in part for preparing fruit butter, but their use must be declared on the label.

4. Principles of Jelly Manufacture

(a) *Pectin Gels*

A gel structure may be prepared by properly combining sugar, water, acid, and pectin. Within certain limits, sugar should constitute about 65% of the mixture and the acidity should be such that the solution has a pH value of about 3.3. The consistency

of a gel may be controlled by varying the quantity of the sugar and acid used in its preparation. Increasing either the sugar or acid content results in a firmer gel. Reducing either the sugar or acid content results in a weaker gel. The lower practical limit for *pH* is 3.1. Below this *pH* liquid separates from the gel as a result of syneresis. This is commonly termed "weeping."

Pectin as it occurs in fruit and in pectin preparations represents a wide range of composition, and molecular weights of over 200,000 are frequent. As a result, the quantity of pectin necessary for gel formation varies with the pectin preparation itself. This quality depends upon the source of the pectin and on its treatment prior to gel formation. For a given pectin preparation a definite minimum quantity must be present to attain gel formation. Above this minimum the firmness of the gel increases with increasing pectin concentration. Gelling power can be determined accurately only by making trial gels under controlled conditions.

The consistency of fruit jellies depends entirely upon the formation of a pectin gel during cooling. The consistency should be tender but sufficiently firm to retain its shape when removed from the container. It should not be sirupy or gummy. Jams, preserves, marmalades, and fruit butters may vary considerably in consistency and may be either more fluid or firmer than jellies. In these products part of the consistency depends on the insoluble fruit solids present and part upon the gelled condition of the liquid. In the preparation of fruit jellies and preserves the water, sugar, acid, and pectin naturally present in the fruit are utilized to obtain a gel.

(b) *Control of Dissolved Solids*

Fruits do not contain sufficient sugars to form a pectin gel and the proper concentration is obtained by adding sugar and by evaporation of water. The amount of dissolved solids present in the finished product is controlled by the quantity of water evaporated during the boiling operation. To attain the proper "finishing point" it is necessary to determine the percentage of dissolved solids at intervals during the boiling operation. In practice, this may be accomplished in a number of ways. The most accurate method having sufficient rapidity for commercial use is by measurement of the refractive index from which the percentage of dissolved solids may be calculated. The elevation in boiling point attributed to the dissolved solids is also employed. A typical fruit juice-sugar mixture containing 65% dissolved solids will boil about 8.7° F. higher than water under the same conditions. A hydrometer may also be used but is less accurate than either of the preceding methods. The "spoon test" or "sheeting test" is commonly employed by the housewife and commercial manufacturer to determine whether the mixture has been sufficiently concentrated to cool to a gel of proper consistency. This test indicates not only that concentration has been sufficient but that the pectin and acid concentrations are adequate to cause gel formation. When these conditions are attained the hot mixture partly congeals and drops from the spoon in sheets. This test requires considerable experience and is not entirely dependable for yielding a uniform consistency.

(c) Control of Acidity

Certain fruits do not contain acid in quantities sufficient to produce a mixture of suitable pH for gel formation. The acidity may be adjusted to the proper point either by mixing with more acid fruit such as lemon or by adding citric, tartaric, or other permitted acids. The hydrogen-ion concentration is most satisfactorily determined by use of a glass electrode. However, in commercial production, formulas have been developed for the various fruits which, when properly applied, result in products of the proper pH range.

(d) Control of Pectin

Fruits differ in their content of pectin, and the jelly-forming capacity of the pectin present varies with the variety of the fruit, its source, maturity, and method of preparation. For these reasons it is more accurate to express the pectin content in terms of jelling capacity or power than in units of quantity present. The jelling power of the fruit may be estimated by determining the viscosity of the fruit juice or extract, or by quantitatively determining the pectin present. Theoretically, the viscosity of pectin solutions would be an accurate index of jelling power because it is a means of measuring molecular size which appears to be an important factor in gel formation. The effect of pH , salt concentration, and the presence of other colloidal substances make this method of determining jelling power inaccurate. Quantitative estimation of pectin is likewise inaccurate. It measures the quantity of pectin present, but does not indicate its jelling power. Accurate determination of pectin is a difficult procedure requiring chemical equipment not available in the average commercial preserving plant. The most satisfactory method for determining the jelling power of fruit components is by preparing a series of test gels. This is accomplished by adding progressively increasing quantities of sugar to samples of the fruit ingredient and boiling the mixtures until the soluble solids content reaches the concentration desired in the finished product. The acid is then adjusted to the proper pH and the samples permitted to cool. The formula of the sample producing the desired consistency is then used in preparing preserves from this fruit component.

For fruit ingredients low in jelling power the desired consistency requires a considerable concentration of the fruit. In commercial practice such fruits are either mixed with fruits high in jelling power or a pectin preparation is added to avoid the prolonged cooking required to attain the necessary concentration and also to maintain the yield. Pectin may be extracted by the preserve manufacturer from fruit products rich in pectin such as fresh apples, dried apple pomace, or dried apple chops.

Commercial pectin preparations made from apple or citrus products are also used. These preparations are sold on the basis of jelly grade which expresses the quantity of sugar, in pounds, a pound of pectin will gel under standardized conditions. This permits a simple calculation of the formula necessary to obtain the desired consistency in a preserve. For example, a fruit may be found by trial to make a preserve of desired consistency when 100 lbs. are mixed with 50 lbs. of sugar and the mixture

concentrated to 65% soluble solids. If to 100 lbs. of this fruit $\frac{1}{2}$ lb. of commercial 100 grade pectin is added, 100 lbs. of sugar instead of 50 may be added to yield the desired consistency. The added pectin thus "carries" the additional sugar used.

Sodium citrate or sodium potassium tartrate may be added to pectin to retard the setting of the gel. This is necessary to permit the escape of bubbles and allow proper filling of containers when preserves are prepared in large batches. A firmer texture is produced for preserves which are to be packed in large containers or preserves intended for distant markets.

5. Manufacturing Methods

(a) Preparation of Fruit Ingredients

Fruit intended for preserve manufacture should be selected and prepared by methods similar to those used in preparing fruit juices as discussed in the previous section. Jellies are prepared from fruit-juice ingredients. The fruit, which may be fresh, frozen, or canned, is usually heated to aid in removing the juice and to increase the quantity of color and of pectin extracted. Firm fruits such as apples and plums are crushed, and water is added to aid in extracting the juice. The actual quantity of fruit-juice component present in extracts which contain added water is based on the soluble solids content of the extract. Rack and cloth presses, described on page 595, are used to press the liquid from the insoluble pulp. If a clear jelly is desired, the extract must be filtered. Settling, centrifuging, fining treatments, starch-hydrolyzing enzymes, and diatomaceous earth may be used to facilitate filtration. The use of pectin-decomposing enzymes is not practiced since such treatment destroys the natural jelling power of the extract. The fruit extract may be concentrated by evaporation or freezing if it is to be shipped or stored for future use.

Fruits may be crushed, sliced, or left whole in preparation for jam, preserve, and marmalade manufacture. Heavy skins and pits should be removed. The fruit may be frozen or canned if it is to be stored for future use. Fruit butters may be prepared from fresh, frozen, canned, or dried fruits. The fruit is passed through a fine screen to give the desired consistency.

(b) Concentration and Finishing

The cooking process, by which concentration is achieved, also causes a partial inversion of sucrose, a partial hydrolysis of pectin, and some loss of aroma and flavor. To reduce the loss in aroma and flavor and pectin decomposition, the boiling period should be as short as possible. Three methods of concentration are used commercially. The oldest is the batch method using an open steam-jacketed kettle. The size of the kettle is usually limited to 50 gal. so that rapid concentration is obtained. A second method employs evaporation under vacuum at temperatures sufficiently low to prevent flavor changes caused by heat. Larger kettles may be employed when evaporation is conducted under vacuum and the mixture is usually heated to a temperature of 180 to 190° F. either before or after concentration to obtain the desired

degree of sugar inversion. The third method involves the use of continuous jelly machines which permit an uninterrupted flow of fruit, sugar, and other ingredients into finished preserves.

In cooking preserves the fruit is heated to a temperature of about 170° F. Pectin, if used, is then added. When dry pectin is used it is mixed with 10 times its weight of sugar to aid in its solution. The fruit mixture is brought to a boil and the remainder of the sugar is added. The mixture is then boiled rapidly to its finishing point. The boiling mixture should be skimmed to remove coagulated material which would detract from the appearance of the finished product.

(c) Packaging and Preservation

When the proper degree of concentration has been achieved, the mixture is allowed to cool to a temperature of about 180 to 200° F. in shallow trays to permit the escape of bubbles. If acid is to be added it is mixed with the product just before filling into containers. The filled containers are then capped. Glass containers are most commonly used for packaging these products though tin cans and wooden tubs are used for the bakery and institutional trade.

When a filling temperature above 190° F. is used no further pasteurization is necessary. The sealed containers are frequently pasteurized particularly when the soluble solids content is not sufficiently high to assure preservation. Sodium benzoate is frequently added to preserves packed in large containers which are difficult to pasteurize.

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Chapter XX

MILK AND MILK PRODUCTS

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I. MILK

It has been estimated that 25 cents out of every dollar which the American farmer receives for his enterprise is derived from the dairy cow. Important as this economic factor undoubtedly is from the standpoint of our national agricultural economy, an even more important factor is the value of the milk and other dairy products to the health and nutrition of our national life.

The majority of the farmers in this country keep dairy cows for milk production, if only for home consumption. Dairy farming is a highly specialized enterprise and the vast bulk of our milk production which has commercial significance comes from producers who devote most, if not all, of their energies to this one activity.

There are four predominant breeds of dairy cattle in this country—Jersey, Guernsey, Holstein, and Ayrshires—but by far the greatest number of the milk-producing animals on our farms consist of grades and scrub cattle. From the point of view of milk production, Jerseys and Guernseys are characterized by their production of relatively smaller quantities of milk rich in fat, whereas Holsteins and Ayrshires produce larger volumes of milk which are relatively lower in fat content. See Volume I, page 409.

1. Basic Requirements for Producing Milk of Sanitary Quality

Although the dairyman must be mindful of scores of different details in the daily pursuit of his work, scrupulous adoption of four basic principles will enable him to produce milk of good sanitary quality.

(a) *Dairy Farm Equipment*

The proper housing of cattle is one prerequisite for good dairy husbandry. This involves protection against the rigorous winters which are customary in those parts of the country where the greatest part of the milk supply is produced. Cow barns should be adequately lighted as an aid in promoting cleanliness, and properly venti-

lated for maintaining the animals in good health. Floors, particularly those portions under the animals, should be constructed of cement or other relatively impervious material to facilitate drainage of liquid waste and as an aid in maintaining cleanliness. Gutters should be provided in back of the ties or stanchions to hold the animal waste until it is removed from the barn. Every dairy barn should be provided with a milkhouse, adjacent to, although not necessarily a part of the barn. Milkhouses should be ventilated, well lighted, screened, and provided with adequate facilities for properly cooling the milk. Under ideal conditions they also should be equipped with hot and cold water for proper washing and sterilizing of utensils. It is a more general practice to perform these tasks in the farm kitchen proper and merely store the clean utensils in the milkhouse between milkings.

From a health standpoint, it is essential that the farm water supply be protected. It is important not only in protecting the farm personnel against the possibility of water-borne diseases, but also for the prevention of direct contamination of the milk which might be placed in utensils washed with contaminated water.

The protection of public health also dictates the necessity for adequate disposal of human waste on the dairy farm. In most cases this involves the construction of privies with tight vaults, self-closing covers, and adequate screening against flies and other insects. Timely cleaning of vaults and the disposal of waste by proper burying should be practiced.

(b) *Health of Herd Animals*

Cows free from tuberculosis and brucellosis will produce milk free from organisms which are likely to cause those diseases in human beings. The organism which is specific for mastitis, namely, *Streptococcus agalactiae* (*S. mastitidis*) will not cause illness in man. Often associated with mastitis, however, are various microorganisms which may cause scarlet fever, septic sore throat, and gastroenteritis. See page 622.

Good dairy husbandry practice calls for the physical examination of all cows in the herd at least once a year by a competent veterinarian. Of course, even strict adoption of this procedure does not relieve the farmer of the necessity of closely supervising the health of his animals and calling for professional help when the need arises. As far as bovine tuberculosis is concerned, all the dairy cattle in this country are now tuberculin-tested, at least in accordance with the provision of the modified accredited area testing plan which has been worked out between the United States Bureau of Animal Industry and the various State bodies exercising sanitary supervision over livestock.

While the blood testing of dairy animals for the presence of *Brucella abortus* has not been too widely adopted, this practice is gradually becoming more common. *B. abortus* is one of the causes of undulant fever in man; consequently, in many localities where the sale of raw milk for human consumption is permitted, the blood testing of dairy cattle is required. Whether or not local ordinances require blood testing, it is indefensible for any dairymen not to include such a precautionary measure if he knows that any of the milk from his herd is to be consumed in the raw state.

(c) Cleaning and Sterilizing of Equipment

Another requirement for the production of good milk is the necessity of properly cleaning and sterilizing all the farm utensils with which the milk comes in contact. Milk drawn from a healthy cow which is reasonably clean at the time of milking should be fairly low in bacterial count; but, if it is placed into an unclean pail or can or drawn into a milking machine which has not been properly washed, the milk will become seeded with bacteria which may rapidly increase in number. The washing of dairy utensils is greatly facilitated if they are rinsed in cold water immediately after use. This should be followed by a brushing in a warm alkaline solution to remove fat, and a subsequent rinsing in fresh warm water to remove all traces of soil and washing compound. The utensils are then ready for sterilizing or bactericidal treatment. For all practical purposes, exposing equipment to steam under pressure for two minutes, or to hot water at 180° F. for the same time period, will produce bacteriologically clean equipment.

The shortage of farm labor brought about by war conditions has caused an increasing number of dairymen to turn to the use of milking machines. It is unfortunate that more thought is given to the time and labor-saving aspect of the milking machine operation than to the sanitary aspects of its use. Many milk sanitarians agree that a milking machine poorly cared for can become one of the greatest contributing causes toward the production of milk of poor sanitary quality. Washing and sterilizing milking machines may be made a matter of routine in the following manner:

1. Draw 3 to 4 gallons of cold water through each milking machine unit immediately after the completion of the milking.
2. Dismantle the machine and brush all parts which have been in contact with the milk with warm water containing a washing compound.
3. Re-assemble and draw clean hot water through the unit.
4. Sterilize by drawing through several gallons of hot water at 180° F. or, alternatively, submerge the parts of the machine in contact with the milk in lye having a caustic soda concentration of about 0.4% or, after it has been washed scrupulously clean from organic material, in a solution containing 200 p. p. m. of chlorine.

Many sanitarians favor dry storage of the milking machine in the milkhouse after sterilization. In such cases the machine should be rinsed with cold water prior to re-use in order to remove any dust which may have accumulated in the interval. The more general practice, however, is to store rubber tubes and parts in a crock containing either a chlorine or lye solution.

(d) Cooling of Milk

The fourth fundamental practice in the production of good quality milk is concerned with proper cooling. Milk left uncooled for any prolonged period will develop large numbers of bacteria. For this reason most health ordinances require that milk produced in the evening be cooled to at least 60° F. Morning milk usually is not required

to be cooled because it is delivered to receiving stations within a few hours after its production.

The use of springs and wells for cooling purposes is fairly widespread, but is not considered very satisfactory by most milk sanitarians. Mechanical refrigeration is, of course, the most satisfactory method used, although good results are obtainable through the proper use of insulated cooling vats where there is an ample supply of cold water or where sufficient supplies of ice are used to keep the water in the vats cold enough to bring the milk down to the required temperature within an hour, at most.

2. Transportation and Inspection of Milk

The milk supplies of smaller cities usually come from near-by areas on trucks which go from farm to farm collecting the milk for delivery to local pasteurizing plants. In larger cities which may draw milk from areas considerably distant, it is frequently impossible to have direct deliveries from the farm to the city plants. In such cases, receiving stations are established near a production area, and the milk produced by a considerable number of farmers is delivered for eventual reshipment in large quantities to the city pasteurizing plants.

To prevent the possibility of a few cans of bad milk contaminating the entire supply, milk should be inspected for quality at the receiving stations before it is combined with other lots in a storage tank. The odor of the cans of milk should be noted and abnormal milk set aside. Temperatures should be observed and sediment tests made periodically. Samples for bacteriological determination should be procured at regular intervals as an aid in determining whether the dairyman uses sound, acceptable practices. Samples should also be taken of each farmer's milk every day for butterfat analysis, since it is practically a nation-wide practice to pay producers on the basis of the fat content of the milk.

After these preliminaries, the milk is dumped, weighed, and cooled to between 36 and 40° F. In larger operations it is pumped into large, insulated, storage tanks to await shipment to the city pasteurizing plant. The farmer's cans in the meantime are run through a mechanical can washer to be returned to him clean and sterilized.

Where large quantities of milk are to be shipped from receiving stations, it is customary to employ large, insulated railroad tank cars or tank trucks. This method has largely replaced the former one of shipping cans of milk in railroad cars using cakes of ice for refrigeration. For tank shipments, the milk is pumped from storage tanks directly into the transportation units, hauled to the city pasteurizing plants which may be several hundred miles away, and then pumped from the trucks directly into the plants. This method of hauling has not only effected large savings in labor but has contributed greatly to the more sanitary handling of milk. Hand dumping of cans of milk has been completely replaced by the use of pumps of sanitary construction. Tank trucks carry as much as 3500-4000 gallons of milk to a load, with the consequent considerable saving of manual labor.

3. Milk-Borne Pathogens

Milk is correctly regarded as one of the best available foods from an all-round nutritional viewpoint and its characterization as "Nature's most nearly perfect food" is well deserved. However, it also serves as an excellent culture medium for many different types of microorganisms. Freshly drawn from the udder of a healthy cow and kept under reasonably sanitary conditions, milk contains relatively few bacteria, and these are usually harmless in character. But, as already mentioned, the failure to keep milk properly refrigerated will, because of its exceptional nutritional qualities, result in a large increase in the bacterial population. Generally speaking, bacterial counts of raw milk provide a reasonably good index of the production methods and handling to which the milk has been subjected. Most milk control agencies have established bacterial standards for market milk.

From an economic standpoint, the development of microorganisms spoils the quality of the milk. Some bacteria utilize the lactose present in milk and convert it into lactic acid, causing an increase in acidity. When this acid concentration is high enough, about 0.3-0.4%, the milk will curdle and sour. Other types attack the milk proteins, causing undesirable flavors and, eventually, putrefaction. While the presence of saprophytic types of bacteria may not have direct health significance, it does have some meaning from an esthetic point of view.

Public health officials are interested in the bacteriological aspects of milk control from a more important point of view than the economic or esthetic. Many disease epidemics of varying magnitudes have been directly traced to a raw milk supply. These have ranged from sporadic outbreaks involving a few cases to explosive epidemics affecting thousands of people and causing hundreds of fatalities. Milk may become a medium of human infection in several ways.

1. The pathogenic organism may be a cause of illness common to both cow and man. In such cases the bacteria get into the milk directly from the animal and then infect the consumers of the raw milk.
2. The organisms may get into the udder of the cow from an infected person, develop, and then be given off in the milk.
3. The milk may become contaminated through outside sources because of careless handling at some point between its production and ultimate use.

A brief consideration of the more common milk-borne diseases and their method of human infection is in order.

(a) *Tuberculosis*

While the organism, *Mycobacterium tuberculosis (bovis)*, causing bovine tuberculosis will seldom infect an adult man, it has been definitely established that children do become affected with certain types of tuberculosis as a result of the bovine tubercular organism. If the cow's udder is infected with tuberculosis, the organisms are given off directly into the milk. Contamination is also caused by feces or urine getting into the pail during milking. Now that tuberculin testing of cattle is practiced on a nation-

wide scale, bovine tuberculosis is no longer considered a major cause of human tuberculosis. This is amply borne out by the following editorial in the *Journal of the American Veterinary Medical Association:*¹

"The lowered incidence of certain types of human tuberculosis following in the wake of the campaign waged against that disease in cattle is an outstanding achievement of American medicine for which the veterinary service is duly credited in the councils of the medical profession. Each report coming to light shows that bone and joint tuberculosis is vanishing in children far beyond the highest expectations. A recent example was the astounding statement by Dr. Arch F. O'Donoghue, orthopedic surgeon of Sioux City, Iowa, where he emphasized before his peers the health benefits from the animal disease control program. We quote: 'In three and a half years starting January 1, 1936, at about the time we began to feel the influence of dairy herd inspection in this state [Iowa], the incidence of bone and joint tuberculosis (bovine type) in children has been exactly 14% of what it was in the ten-year period between 1926 and 1936; a decrease of 86%, probably entirely due to tuberculin testing and inspection of dairy herds and the removal of the reactors.' "

(b) *Undulant Fever*

Brucella abortus, the organism responsible for contagious abortion in cattle, is one of the etiological agents causing undulant fever in man. This organism is found in the milk of infected cows. Consumption of such milk is likely to produce undulant fever. There is considerable danger from this disease wherever raw milk is consumed, although many health jurisdictions now require the testing of dairy cattle for contagious abortion where raw milk is legally permitted to be sold. Because the symptoms of undulant fever were formerly often confused with those of numerous other diseases, until satisfactory clinical methods for distinguishing the disease were developed there was but scanty recognition of the frequency with which the disease occurred.

(c) *Scarlet Fever*

This disease is caused by several forms of *Streptococcus pyogenes (hemolyticus)* Group A. When milk is involved, the person milking the cow may have had a sore throat or may unwittingly be a carrier of the causative organism. From this infected individual, the organism may get into the udder of the cow, usually through some injury. Growth and development of the organism take place and, after a while, large numbers of the pathogenic streptococci are given off in the milk.

(d) *Septic Sore Throat*

This disease is regarded as a milder manifestation of the same types of hemolytic streptococcal infection which cause scarlet fever. The same form of organism may cause sore throat in one person and scarlet fever in another, depending, perhaps, upon the virulence of the particular infection and upon the resistance of the individual affected. Since scarlet fever is attributed to the toxin produced by the bacteria, and septic sore throat is a result of the increase in the number of organisms themselves, the same forms of hemolytic streptococcus can cause septic sore throat in individuals

¹ *J. Am. Vet. Med. Assoc.*, 100, 145 (1942).

immune to the toxin. Contamination of the milk is brought about in the same manner as described for scarlet fever.

(e) *Typhoid Fever*

Milk merely serves as a vehicle for bringing this infection to the public. Milk may become contaminated from polluted water containing *Enterobacter typhosa*. Polluted water or droplets of polluted water may find their way into cans of milk during vat cooling, or contaminated ice may get into cans through careless handling. Carriers of the disease may also, through ignorance or carelessness, contaminate the milk. Indeed not only the spread of typhoid fever by means of polluted milk, both raw and pasteurized, is to be considered in this category but all types of enteric diseases may be spread by means of postpasteurization contamination.

It may be noted that one of the worst milk-borne outbreaks on record involved typhoid fever. This happened in the City of Montreal, Canada, in 1927, when nearly 5,000 people were stricken and 453 fatalities resulted.²

(f) *Gastroenteritis*

Staphylococcus aureus is occasionally responsible for mastitis in cows. It is capable of producing a toxin which causes gastroenteritis in human beings.

(g) *Diphtheria*

This disease, caused by the organism, *Corynebacterium diphtheriae*, may also be milk-borne, contamination occurring by infected persons coming into direct contact with the milk at some point between production and consumption.

4. Pasteurization

Since the potential danger of milk as a carrier of human infection is definitely established, it is the responsibility of health officials to eliminate or reduce to the lowest possible degree the likelihood of milk-borne infections. From a practical point of view, this problem is best solved by the process of pasteurization. Pasteurization is, essentially, the application of a sufficient amount of heat to a product for a sufficient period of time to destroy any pathogenic bacteria which may be present.

In establishing standards for the pasteurization of milk, early investigators had to take into consideration factors such as: the minimum temperature and time of exposure necessary to destroy the most heat-resistant types of harmful bacteria; adequate safety factors needed beyond the minimum in order to take care of unforeseen or abnormal conditions; effect of the treatment upon the flavor and appearance of the milk; effect of the treatment upon the nutritive quality of milk; and the economic feasibility of the process.

² U. S. Pub. Health Service, Rept. Special Board, *Am. J. Pub. Health*, 17, 783 (1927).

At present there are two methods of pasteurization generally acceptable for the processing of milk:

(a) *The holding method*, which involves the heating of every particle of milk to at least 142–143° F., holding it at that temperature for at least 30 min. and immediately cooling it thereafter to at least 50° F.

(b) *The high-temperature, short-time method*, which calls for the heating of every particle of milk to at least 160° F., holding at that temperature for at least 15 sec., and immediately cooling it thereafter to at least 50° F.

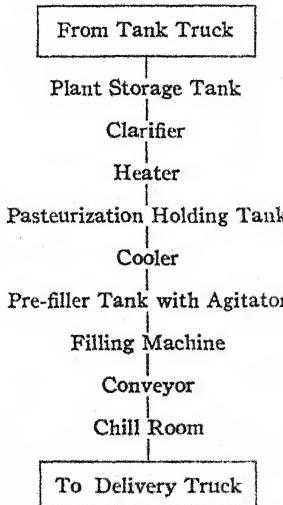


Fig. 141.—A simple flowsheet of the equipment used in pasteurizing milk by the holding method.

Short-time pasteurization is a modification, in which adequate control instruments are employed, of one of the earliest methods of pasteurization used in the milk industry, *flash pasteurization*. This process involved the quick heating of milk to about 160–165° F. followed by immediate cooling. There was no deliberate holding of the milk at the high temperature for any appreciable time interval. Methods for automatically controlling temperatures and recording them were not in existence at the time and outbreaks of disease traceable to milk which had allegedly been flash-pasteurized brought this method of processing into disrepute. Milk sanitarians and manufacturers therefore turned to more positive methods of pasteurizing, eventually developing and perfecting the holding method and the short-time method.

Other types of pasteurization are mentioned in Volume I, page 415. Different aspects of this subject are discussed in this volume on pages 68, 320, and 600.

(a) *Batch-Type Pasteurizers*

The batch type of pasteurizer is the simplest form of holding method pasteurizer. It may be heated by means of a heating jacket around a tank into which milk is dumped

or pumped, or by coils within the vessel. In the latter, the coils are rotated inside the vessel so that the milk is heated and stirred at the same time.

If this type is used, coils placed in a vertical position are preferred from the standpoint of sanitary construction. While the entire pasteurizing operation may be performed in such tanks, it is frequently the practice to preheat the milk before it is placed in these vats. Hot water or steam is circulated between the double walls of the jacketed tank or through the coils until the desired temperature is reached. The temperature of the heating medium is maintained by circulating hot water between the walls or in the coils until the pasteurizing temperature is reached. The milk is

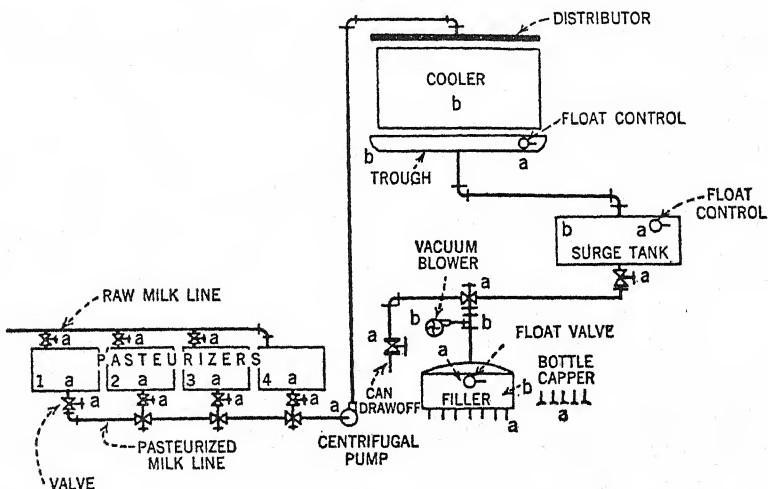


Fig. 142.—Diagram showing a batch pasteurizing system. The letters *a* and *b* indicate steps in the sterilizing operation as follows: *a*, immerse parts in sterilizing solution before or during assembly; *b*, spray or flood with sterilizing solution. In the batch pasteurization of milk or cream, the assembly should then be completed, and, beginning at pasteurizer 1, the gate valves opened to flood the manifold sections.³

maintained at this temperature for at least 30 minutes and is then cooled. Cooling may be performed in the same vat or by a separate cooler. Each jacketed vat should be provided with an agitator to prevent stratification of the heated milk and to assure that every particle is sufficiently heated.

In addition, pasteurizing vats should have both an indicating and a recording thermometer. The latter is tied in with a clock so that the entire device provides an accurate record of the degree of heat to which the milk is exposed and the duration of the exposure. Indicating thermometers are less likely to get out of order than recording thermometers and should be used to check the latter. In the case of both types of thermometer, the bulbs should be so placed in the vat that the temperatures

³ *Food Industries*, 16, No. 3, 89 (1944).

indicated reflect the actual milk temperatures. Placing the bulbs too near the inner surfaces of the pasteurizer may cause activation of the thermometer by the heating medium, and an incorrect impression of the milk temperature would be obtained.

Pasteurizing tank outlet valves should be of a flush type and built closely coupled to the body of the vat to avoid dead ends and the pocketing of milk. Milk which has become pocketed is not likely to reach proper pasteurization temperatures or retain such temperatures throughout the entire holding periods. Outlet valves should, in addition, be provided with leak protector grooves to prevent the likelihood of insufficiently held milk leaking past the valve and into the pasteurized milk lines during the heating and holding operations. By the same token, valves on raw milk inlet lines should be of a leak protector type.

In order to determine from the recording charts whether or not milk has been held for a sufficient period of time, it is necessary to know the filling and emptying times of the pasteurizing vat. For example, the recording of temperature starts as soon as the milk level touches the thermometer, which is usually in the lower part of the pasteurizer. If only 30 minutes of holding are allotted from this point on, it is clear that the milk added after the bulb is covered will not have been held a full 30 minutes. Similarly, although a careless operator can start drawing off milk before the expiration of the full 30 minutes, the chart may show a full holding period because the thermometer will continue to register until the milk has fallen below the level of the thermometer bulb. With this type of pasteurizing equipment, therefore, it is necessary for the temperature recording chart to show that the milk has been at pasteurizing temperature for 30 minutes, plus the filling time, plus the emptying time, before one can be sure that the entire batch of milk has been held for the legally required pasteurizing period.

The unit described above represents the simplest type of commercial pasteurizing apparatus to be found. Most systems used for commercial operations, even though they may be small in size, do not depend upon the pasteurizing vat alone to do the heating, holding, and cooling. Milk is usually pumped from the raw milk storage tank through a heater in which it is brought up to pasteurizing temperature and then run into the pasteurizing vat or holding tank for the required holding period. Heaters are of three general types:

1. Internal tubular, which consist of a series of connected metal pipes within pipes. The milk is pumped through the inside pipes while hot water is pumped through the surrounding pipe system.
2. Surface heaters, which consist of a series of pipes or conduits of some other form through which hot water is pumped. At the same time, cold milk is permitted to flow down the outside surfaces of these pipes to become heated. Such heaters are either enclosed in a metal covered cabinet or are placed in a glass enclosed room to prevent air-borne dust particles from getting into the milk.
3. Plate-type heaters, which are made up of a series of corrugated metal plates placed close to each other and held together in a press. The milk flows on one side of a plate while hot water, which is used to heat the milk, flows on the other side. The plates are rimmed with rubber gaskets to prevent leakage.

After the hot milk has been held for the required period, it is pumped through the cooler for the final step in the pasteurizing process. Coolers are usually of the surface

or plate types identical in construction with the heaters described above. Brine, ammonia, and fresh water are all used as cooling media. In some installations combinations of the three may be used: thus, one section of the cooler may be arranged for use with fresh water, while the next section of the same cooler may be hooked up for ammonia or brine cooling.

Pasteurizers of the batch type as described above are manually operated, that is—dependence is placed upon some individual to let the milk into the vat, to supervise its holding for the required period of time, and to open the outlet valve for emptying at the end of the pasteurizing period. It is possible to hook up a series of two, three, or more of these individual batch pasteurizers and operate them as a unit. In such cases the operation is usually arranged so that, as soon as the fully pasteurized milk has been drawn from one vat, the holding time on the next vat will have been completed and the milk will be ready for cooling and bottling.

Batch operations, either in single or multiple arrangements, work out fairly satisfactorily for relatively small pasteurizing operations. But there are certain weaknesses inherent in their use. Since they are manually operated, their successful use depends upon the skill of the operator. Improper pasteurization because of under-heating and underholding may easily occur. On the other hand, it is equally likely that milk will be overheld, thus leading to impairment of flavor and to a reduction of cream line or cream volume of the bottle of milk. Unless the batches are properly synchronized, the bottling operation may be unnecessarily held up because the flow of milk from the pasteurizer is not continuous. This may involve a costly loss of time from the standpoint of economical plant operation.

(b) *Continuous-Type Pasteurizers*

To overcome these disadvantages, dairy engineers, have developed various types of automatically controlled, continuous-flow pasteurizing systems. The automatic controls are timing devices which regulate the opening and closing of the inlet and outlet valves of pasteurizing systems so that the milk is held for the required pasteurizing period. Continuous flow systems may consist of a series of vats (usually 4 to 8) all hooked together and operating under a single automatic valve control device, or they may consist of a very large tank separated into 4 to 8 compartments. In all such operations it is the practice to use a separate heater to bring the milk up to pasteurizing temperature. The hot milk is pumped into the holding tanks which are well insulated to keep heat loss at a minimum. The tanks are filled consecutively. The system is so timed that, as the last tank or compartment in the unit is being filled, the first tank of milk has been held the full 30 minutes and is simultaneously emptied.

(c) *Short-Time, High-Temperature Pasteurizers*

This type of pasteurization unit consists, essentially, of a heater, a holding tube, and a cooler. Heaters and coolers are identical in type with those found in the con-

ventional holding systems. The holding tube is a piece of sanitary piping of such length and diameter as to require 15–16 seconds for the milk to pass its entire length when forced through by a pump of given capacity and set speed.

Since the period of exposure at pasteurization temperatures is very short in this type of unit, it is extremely important that effective controls be used to make certain that no milk which has been insufficiently heated will get past the holding tube. This is accomplished by means of a flow diversion valve. The valve is usually placed immediately after the holding tube and is actuated by temperature changes in the milk. The valve is so set that it will remain in the open or forward flow position

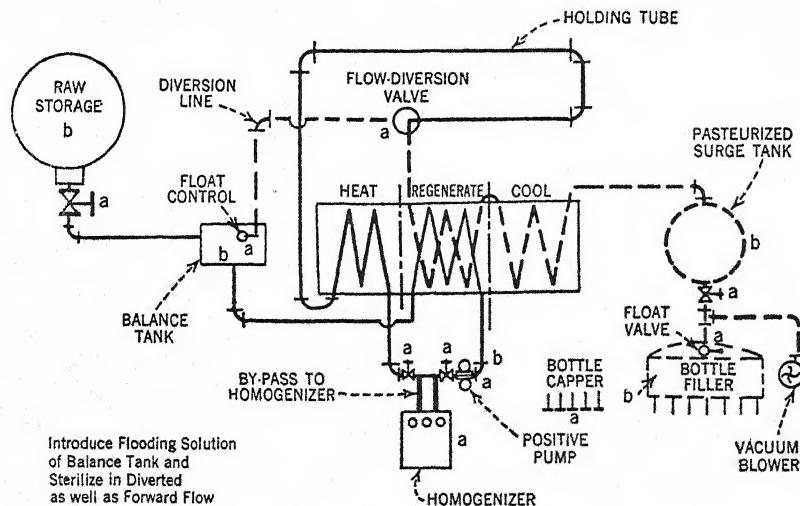


Fig. 143.—Diagram of high-temperature-short-time pasteurization operation. The letters *a* and *b* indicate steps in the sterilizing operation as follows: *a*, immerse parts in sterilizing solution before or during assembly; *b*, spray or flood with sterilizing solution.³

only as long as the milk from the heater is at least up to pasteurization temperature (160–161° F.). The instant the milk drops below the established pasteurization temperature by as little as 0.1° F., the position of the valve changes from the forward flow to the diverted position, thus preventing the passage of milk which has not been adequately heat-treated. The diverted milk goes back into the heating unit, and the forward flow is not resumed until a sufficient increase in temperature has been achieved to cause the valve to be opened again in the forward flow direction.

There are several other types of pasteurization systems to be found and many variations of the general types described above. The foregoing is intended to give a broad picture of the principal kind commonly employed in this country. Each manufacturer of dairy equipment has special features peculiar to his own apparatus and each make undoubtedly has particular advantages and disadvantages.

(d) Principle of Regeneration or Heat Exchanging

No description of the pasteurization process as it is now carried on commercially would be complete without mention of regeneration. The purpose of regeneration is utilization to the greatest extent possible of the heat energy involved in pasteurization. This is accomplished by taking the milk which has already been heated and held and using its heat to warm or preheat the rest of the raw milk which is still to be pasteurized. At the same time the removal of the heat from the pasteurized product causes a precooling of the latter, thus utilizing the heat energy to a maximum and reducing the cost of the pasteurizing operation.

Heat exchangers are of two general types: The heat transfer is effected from milk to milk; the transfer is made from milk to water to milk. In the case of milk-to-milk heat transfer, the regenerator may consist of two concentric pipes, with the hot milk flowing in one pipe and cold milk flowing through the other; or it may consist of a section of connected horizontal pipes with hot milk on the inside of the coil and cold milk on the outside. A third type of milk-to-milk regenerator may be made up of a series of metal plates with the hot milk flowing on one side of the plates and cold raw milk on the opposite side. In the water-to-milk-to-water regenerator, the water which is used to effect the heat transfer is in a closed circulating system; the heat from the pasteurized milk is transferred to water which is being used for precooling purposes; and the water thus warmed is then used to preheat the raw cold milk which is about to be pasteurized.

5. Bottling

Upon completion of the pasteurizing operation the milk is ready to be placed in the bottle. In small operations, milk is pumped or run from the cooler directly into the bottle filling machine. In operations of any considerable magnitude it is practically essential to have a surge or storage tank for the pasteurized milk before the filler is reached. The necessity for the surge tank arises because stoppages in the bottling operation frequently occur and the bottle filler would overflow unless the entire pasteurizing process were stopped at the same time. Since it is most undesirable from an operating standpoint to have this happen, surge or balance tanks are provided to permit the continuation of pasteurization at least for a sufficient time to overcome temporary interruptions in bottling. The size of the surge tank varies with the size and character of the operation. Where bottles only are filled, the surge tank must be relatively larger than where milk is also filled into large cans, because the can filling operation may continue even when the bottling operation has stopped.

Milk bottle fillers, except in small hand operations, are bowl-shaped containers rotating on a pivot and provided with outlet valves on the bottom. They are geared in speed to the bottle washing machine. As the cleaned and sterilized bottles are conveyed from the washer to the filler, the bottles are automatically pressed against the filler valves which open and permit milk to run into the bottle while the machine

rotates. In some machines the filling is done by gravity, while others employ a vacuum principle. Bottle caps are applied mechanically immediately after the bottle leaves the filler and hoods or cover caps are next put on.

(a) *Bottle Washing*

While the washing of milk bottles by hand is still practiced in very small dairy operations, the most feasible manner of washing milk bottles, both from the standpoint of efficiency and speed, is by the use of the soaker-type washer. There are many different types of such washers but all are designed to provide a prolonged period for the bottles to soak in a washing solution which usually contains caustic soda. The machines have an endless chain of pockets arranged in rows for holding the bottles as they pass through the various phases of treatment. After the caustic soak, the bottles are subjected to various sprays or brush treatments and finally to a sterilizing treatment usually with chlorine. The more modern machines are also equipped with pre-rinse sprays for softening and removing some of the bottle soil before immersion in the soaking compartment.

The period of soaking, the alkali concentration, and the temperature of the soaking solution have a bearing on the ultimate cleanliness and sterility of the bottle. A five-minute soak in a 3% caustic soda solution at 135° F. has been found effective in the cleansing of milk bottles. Care should be exercised in testing the soaking solution at the beginning of and during the operation since the concentration of sodium hydroxide diminishes because of the carry-over of prerinse water and also because some of the caustic solution itself is carried away by the bottles leaving the soaking compartment. See also page 636.

It is advisable to have the machines equipped with a dial type of indicating thermometer easily visible to the operator, and connected to the solution tank to make sure that soak temperatures are adequately maintained.

Checking the spray jets frequently to see that they have not become clogged or knocked out of alignment should be made a routine plant procedure.

(b) *Bottle Sterilizing*

Sterilization is finally achieved by exposing the washed bottles to one or more chlorine sprays. A minimum strength of 10 p. p. m. is customarily employed for a period of at least 10 seconds. Because the chlorine solution is usually recirculated for reasons of economy it is necessary to keep introducing fresh chlorine stock solution into the chlorine tank to make up for a loss in strength. The solution should be tested at regular intervals to ascertain if the necessary strength is maintained.

It is also advisable to provide the chlorine solution tank with some means of cooling because the washed bottles normally come out of the washing machine at about 100° F. Since they are immediately filled with milk after the chlorine rinse, there is some likelihood of warming up the milk upon bottling unless the bottles are first cooled.

6. Filtration and Clarification

Even though farmers use ordinary care in the production of milk and strain it before it goes into the shipping cans, and despite the fact that milk is dumped through fine meshed strainers at receiving stations, market milk, when it arrives at the pasteurizing plant, still contains a considerable amount of fine sediment and other foreign material. Operators take considerable pains to remove these foreign substances, for the presence of such foreign material in the consumer's bottle will lead to dissatisfied customers and loss of trade. Filtration or clarification is the method commonly used to accomplish this removal.

Milk may be filtered cold before it starts through the pasteurizing system or the filters may be placed in the pasteurizing line, usually after the milk has been pre-heated. The advocates of cold milk filtration claim the following advantages over hot milk filtration:

1. The milk can be aerated, thus eliminating off-flavors which may be present.
2. There is no build-up of thermophiles such as may occur in hot milk filters.
3. More dirt is filtered out. In the hot method, some dirt is rendered soluble and consequently passes through the filters.

The chief advantage of hot milk filtration lies in the fact that there is little or no loss in butterfat. When cold milk passes through a filter cloth, some of the fat adheres to it, entailing a loss. This collecting of the fat on the filter cloths also slows down the rate of filtration.

Clarification is increasing in popularity as a means of removing foreign material from milk. It undoubtedly does a more effective job than filtration. In this method the foreign particles are separated from the milk by centrifugal force. Clarification is practically a necessity where homogenized milk is produced because of the ability of the clarifier to remove a large portion of the leucocytes and epithelial cells which are present in milk. These cells are sloughed off from the udder tissue in varying numbers, depending in part upon the period of lactation and the physical condition of the cow. Cows in an advanced state of lactation or suffering from udder injuries or infections are likely to shed large numbers of leucocytes in their milk. During ordinary pasteurization, these cell bodies remain in suspension and are not visible; but, if the milk is homogenized, the cells precipitate and appear in the form of a grayish sediment on the bottom of the bottle. Filtration methods will not remove leucocytes appreciably.

7. Homogenization and Fortification

Homogenization of milk is the process by which milk is forced through a small opening under great pressure, up to 3000 pounds per square inch, thus causing the fat globules to break up into smaller sizes and bring about a more or less stable dispersion of the butterfat throughout the mass of the milk. See Volume I, page 416. Homogenization reduces the curd tension of the milk, makes it more readily digestible, and, in the opinion of many people, improves its palatability.

Homogenization has the effect of activating the enzyme, lipase, in milk, thus causing a slightly rancid flavor. This difficulty can be completely overcome, however, if the milk is pasteurized immediately before or immediately after homogenization, the heat treatment rendering lipase inactive before the off-flavors have an opportunity to develop.

Vitamin D milk is market milk which has been fortified in such a manner as to give it antirachitic properties. Milk is, for all practical purposes, deficient in this essential vitamin. Because it is universally used in the feeding of infants and children and because it has such large amounts of calcium and phosphorus which are also essential for proper bone development, milk is considered a favorable vehicle for supplying vitamin D needs. Three methods of fortification are commonly used:

1. *Feeding Irradiated Yeast in Controlled Amounts to Lactating Cows.*—After several weeks of feeding, the vitamin appears in the milk in sufficient quantities to have antirachitic properties. This method is relatively more costly than the others and is usually used on certified dairy farms where feeding practices are carefully controlled.

2. *Direct Irradiation of the Milk.*—Here, ultraviolet light from a carbon arc or quartz mercury vapor lamp is played upon a thin film of flowing milk. The equipment first used for irradiating milk produced only about 135 U. S. P. units of vitamin D, but the latest types of irradiators can now produce a potency of over 400 units of vitamin D per quart of milk. The usual plant practice in milk irradiation is to treat the raw milk in advance of pasteurization, since the latter has no effect upon the potency or stability of the vitamin. Irradiation involves the use of a fairly expensive piece of equipment, but is nevertheless employed to a considerable extent.

3. *Addition of Vitamin D Concentrate to the Milk.*—The concentrate is usually in the form of irradiated ergosterol or fish-liver oil made up in an emulsion of either evaporated milk or one of the edible vegetable oils. It is commercially prepared under carefully controlled conditions and sold to milk plant operators in convenient small containers. Given amounts of concentrate are thoroughly mixed with the milk before pasteurization. Milk is usually fortified with 400 units per quart. This method is the one most widely used because of its simplicity and the fact that it involves little or no extra handling or equipment.

Testing the potency of vitamin D milk is done by bioassay methods. A number of rats are kept on a diet free of vitamin D, to produce rickets. After the rats are prepared, controlled quantities of the vitamin D milk are mixed into the rat diet and fed over a period of time. The rats are then killed and the degree of bone healing is taken as an indication of the antirachitic value of the milk. Most vitamin D testing is done by commercial laboratories which specialize in this type of work.

8. Technical Control in the Plant

No matter what the size of a plant operation may be, some degree of technical control must be practiced if a uniformly good quality product is to be obtained and if compliance with public health regulatory requirements is to be achieved. Not all plants may be able to engage the services of a highly trained dairy technologist but commercial laboratories may be hired for laboratory or testing work, or some of the regular dairy workers can be trained to perform the simpler but nevertheless essential control testing.

An operator cannot hope to put out a satisfactory product if his raw material is poor to begin with. Each lot of raw milk coming into a plant should be sampled and tested for butterfat content and acidity before pasteurization. Care should be exercised to get a representative sampling. If the milk comes in by tank, each load should be thoroughly agitated. If shipments are received in cans, it may be possible to get a fairly good picture by sampling an aliquot number of cans or a sample may be taken from the storage tank after it is filled. This procedure does not apply to receiving stations at which samples are taken of each farmer's delivery. Milk which fails to measure up to the prevailing butterfat and total solids standards or which has an acidity in excess of 0.18-0.20%, calculated as lactic acid, should not be used for market milk. The normal acidity of milk is 0.15-0.16% calculated as lactic acid. See Volume I, page 404.

(a) *Bacterial Control*

As stated previously, the bacterial population of milk is one of the best indices for judging the sanitary quality of milk, both raw and pasteurized. For this reason, all public health agencies establish bacterial standards for milk. A high count is not necessarily an indication of unwholesomeness, although some investigators have attributed intestinal disorders in children to pasteurized milk containing excessive numbers of bacteria. However, a high count does indicate some fault or faults along the line between production and final distribution.

Samples of the raw milk should be taken to ascertain whether the milk conforms to the bacterial standards set by public health agencies. For a quick determination before the milk is pasteurized the Breed method of direct microscopic examination is practical and satisfactory, and enables an operator to reject a shipment of unsatisfactory raw milk on the basis of a grossly excessive count. The method requires a certain degree of skill and experience, although a person need not be a bacteriologist in order to make the count properly.

Another method for making bacterial counts of milk is the Standard Plate method, which is a laboratory method and must be performed by a trained technician. Results of the plate method are not available until two days after the plating. The method is useful for the purpose of getting a general bacteriological picture of the source of the raw milk.

Bacterial counts should also be made of pasteurized milk to determine whether or not local standards have been met. In this case, the Standard Plate method is used, since direct microscopic examination would reveal not only those organisms which survived pasteurization but also those which were killed in processing but not disintegrated. Excessive counts in pasteurized milk may generally be attributed to one or more of the following factors:

- (a) Excessively high counts in the raw milk.
- (b) The presence of thermoduric bacteria in the raw milk supply.
- (c) Improper washing and sterilizing of the pasteurizing equipment.
- (d) Improper washing and sterilizing of containers such as cans and bottles.

- (e) Open seams in equipment.
- (f) Excessive holding of heated or partly heated milk in various parts of the pasteurizing system because of repeated shutdowns in the operation.
- (g) Excessive foam in the holders.
- (h) Insufficient heating and holding of the milk.
- (i) Inadequate cooling of the pasteurized milk or failure to keep it properly refrigerated after bottling.

In early studies in dairy bacteriology it was assumed that pasteurization destroyed about 99% of the bacteria in milk. As technological and bacteriological progress was made, we learned that the number of bacteria killed depended upon the kind of organisms present, many of which may be heat resistant, and also upon the total numbers present in the raw milk. The greater the number of bacteria in the raw milk, the greater is the number which will survive pasteurization. There are two general groups of bacteria which survive pasteurization to the detriment of the product—thermoduric and thermophilic.

Thermoduric Bacteria.—These are organisms which survive the heating and holding temperatures of pasteurization. They are frequently present in the milk as drawn from the cows; and failure to wash and sterilize milking utensils thoroughly affords an excellent opportunity for their growth and development. Dirty milking machines in particular are a common source of thermoduric bacteria.

To determine whether or not high counts in pasteurized milk are due to such organisms, it is necessary to resort to laboratory pasteurization of raw milk supplies. A sample of raw milk is plated. Milk from the same source is also put through a process of laboratory pasteurization which simulates the treatment given in commercial pasteurization, and another plate made of the laboratory treated milk. Survival of bacteria in excess of established standards is evidence of the presence of thermoduric organisms and should lead to investigations of the farms producing the milk. Where the blended product of a receiving station is found to contain excessive thermoduric bacteria, an inspection of the dairies using milking machines will frequently reveal the source of the trouble.

The equipment necessary to perform laboratory pasteurization consists of an insulated water bath, the temperature of which can be automatically regulated by thermostatic controls, an agitator to keep the bath temperature uniformly at the pasteurizing range, test tubes and racks, and a pasteurizing thermometer inserted for check purposes in one of the tubes. Thin nickel alloy or other metal tubes with one end stoppered are preferable to glass since they permit more rapid heat transfer. The tubes should be placed in ice water immediately after the holding period to simulate commercial cooling.

Thermophilic Bacteria.—These organisms not only survive but actually multiply at relatively high temperatures, even those of pasteurization and holding. There are consequently abundant opportunities for their development in the pasteurizing operation. Most thermophilic organisms originate from soil, manure, and feeds, in contradistinction to thermoduric bacteria, which are associated with improperly cleaned

milking machines, cans, and other farm utensils. Hence thermophiles, too, originate at the farm. An excessively prolonged pasteurizing operation is likely to cause the development of thermophiles. Similarly, pocketing of warm milk for prolonged periods in pipe lines, vats, filters, etc., because of shutdowns encourages their development. The presence of open seams in equipment provides areas which are virtually impossible to clean and sterilize properly, and furnishes a good place for thermophiles to harbor and develop. Accumulations of milkstone also frequently contain these organisms and effect the seeding of the milk as it passes over the areas affected.

When an excessive amount of foam gets into the milk, it accumulates in the holding tanks. Filling and emptying of the holders causes the foam to ride up and down in the tank. Thermophiles present in the foam bring about a seeding of each batch of milk as it enters the holders.

While no disease in human beings has been traced to thermophilic bacteria in milk, and they are therefore probably not pathogenic, they are nevertheless important for a number of reasons. In the first place, every market-milk plant operator is faced with the necessity of meeting local bacteriological standards. This cannot be done if his equipment is badly contaminated. Thermophiles may indicate either faulty plant processes or equipment or a thermophile-seeded raw milk supply. Secondly, thermophiles have an adverse effect upon the flavor of milk and will eventually cause spoilage.

(b) *Plant Equipment*

Since milk is such an excellent medium for bacterial growth, the importance of carefully cleaning and sterilizing equipment is clear. Neglecting even a small part of the apparatus may nullify a great deal of the effort which has gone into the entire cleaning operation.

It should become a fixed practice to pump cold or lukewarm water through the pasteurizing system as soon as the pasteurizing operation is finished. This will remove a great deal of the milk residue, and more particularly will prevent its drying on the equipment. The equipment should then be completely dismantled and brushed with a good washing compound. There are many satisfactory commercial preparations which are designed for this purpose, the choice depending upon the type of operation, the kind of equipment, hardness of the plant water supply, cost of the compound, and other factors. It is best to have a separate wash tank for small parts and a rack for draining pipes or similar equipment after washing. A warm water rinse completes the cleaning.

It is good plant practice to treat equipment periodically for the removal of milkstone. In fact, some plants pump milkstone remover through the pasteurizing system daily, although there is some danger of corrosion of metals by such practices. Where milkstone removers are used, it is customary to circulate the remover through the system immediately after the cold water rinse.

Sterilization of the equipment is the next step to be taken. Three different methods are generally employed, sometimes singly and at other times in combination.

Steam Sterilization.—This method is entirely satisfactory if the pasteurizing system is tight and completely enclosed, and if there is an abundant supply of steam under sufficient pressure. Pipe lines, plate heaters and coolers, and internal tubular heaters and coolers may be adequately sterilized by live steam; but this method is not very effective for tanks, vats, surface heaters and coolers, fillers, etc., because steam pressure cannot be maintained. Some operators use steam where it is effective and either hot water or a chlorine solution on the rest of the equipment.

Hot Water Sterilization.—A temperature of at least 180° F. should be maintained when hot water is used for sterilization. It should be applied to every part of the equipment surface. In order to make sure that every part of the unit has been properly treated, the temperature of the water coming out at the end of the system should be at least 180°, for it must be remembered that considerable heat is lost in passing through the equipment. Because such use would cause the pumps to wear out prematurely, it is not good practice to use the regular milk pump to pump water through the unit. A portable auxiliary pump should be provided for this purpose.

Chlorine Sterilization.—The use of chlorine solutions for sterilizing purposes has become very general in recent years. Solutions containing at least 100 p. p. m. of available chlorine are pumped through the system. Since the chlorine becomes dissipated in contact with organic matter it is essential that the equipment be scrupulously clean before the sterilizing treatment. See page 227. The operator should test the concentration of the chlorine after it has gone through the unit to ascertain that the solution is still of the required strength.

Tank trucks and storage tanks are usually sterilized by applying to all surfaces a chlorine spray containing at least 250 p. p. m. of available chlorine. To be reasonably sure that all surfaces are reached, the solution should be under sufficient pressure to provide a fine spray.

(c) Milk Containers

Regardless of the precautions taken to sterilize and wash processing equipment properly, the effort will be largely wasted if the pasteurized milk is placed in a can or bottle which has not been properly washed and sterilized.

Bottle Washing.—The so-called soaker type of bottle washers probably provide the most effective kind of milk bottle washing. See page 630. The soaking tank usually contains a caustic solution equivalent to 2-3% sodium hydroxide at a temperature varying between 135-150° F. Some machines have a series of tanks in which the temperature of the solution is gradually stepped up, tank by tank. The length of time in the soaking compartment may vary from three to seven minutes, depending upon the speed of the machine and its make. Generally speaking, the longer the soaking time, the more efficient is the washing.

The bottles are then subjected to mechanical brushing or a series of spray treatments under pressure to remove all traces of the soaking solution. Sterilization is achieved by pumping a chlorine solution containing 10-15 p. p. m. of available chlorine into the

inverted bottles just before they emerge from the machine. The chlorine solution is frequently recirculated; but, whether or not this is done, the apparatus should be equipped so that fresh chlorine solution can be fed from a stock solution into the tank to keep the necessary effective concentration.

A routine procedure at every plant should be a check of the chlorine concentration a number of times during the run. The same principle should be followed with respect to the caustic soda solution in the soaking tank, to make up for the dilution which occurs during the operation.

Can Washing.—Mechanical washing of milk cans is practically a necessity where a large number are involved or where they must be washed in a short period of time, as is the case in milk receiving operations. Two general types of mechanical washers are employed, the straight-away and the rotary. In either case the washing is accomplished by passing the cans over a series of spray jets under pressure. The first jets provide a prerinising of the can with either cold or slightly tempered fresh water. The next treatment involves spraying of a washing solution into the can. These washing solutions usually have trisodium phosphate or sodium metasilicate as a base, and should contain a wetting agent. The alkalinity should not exceed 0.05% because of the corrosive effect upon the tinned surface. This treatment is followed by a fresh water postrinse. The next step is a so-called sterile rinse, with hot water succeeded by steam treatment under pressure for sterilizing purposes. A blast of hot air is then blown into the can to effect rapid drying. This last step is very important since failure to dry a can thoroughly will permit the development of any bacteria which may have survived the treatment; a thoroughly dry can, however, will not afford much opportunity for bacterial survival.

There have been a few innovations in can washing methods which have appeared in the past few years. These are briefly mentioned here because, they give some promise of excellent results. One change involves the use of acid cleaners instead of the customary alkaline washing compound. See page 224. The advantages claimed are: better bactericidal effect; and reduction or elimination of milkstone formation in the milk cans. It is also maintained that they have a less corrosive effect upon the metal. These acid cleaners, generally sold under trade names, contain mild organic acids combined with a wetting agent. The second innovation involves the use of a solution of gluconic or other mild organic acid which is injected into the steam at the time of sterilization.

In checking the efficiency of any can washing operation, the pressure of the spray applications and the volume of the water or solution in each position should be great enough to remove mechanically the soil adhering to the cans. The jets must be properly centered and kept free from rust, scale, and accidental clogging.

(d) *Pasteurization Control*

From a public health standpoint (and all milk pasteurizing plants in the country operate under the control of some official agency), the test of a pasteurizing plant's effectiveness is measured by the completeness with which the milk is pasteurized.

Most pasteurizing ordinances define pasteurization as the heating of *every particle* of milk to a given temperature for a stated period of time. Thus, the pasteurizing of a batch of milk is partly nullified if even a small amount of raw milk is permitted to leak past a valve and into a tank during holding. Nor is the requirement for pasteurization legally satisfied if the milk itself is at the proper temperature while the foam layer on its surface is considerably cooler.

To be sure, most large pasteurizing operations are automatically controlled as to time and temperature and are provided with automatic temperature recording devices. There may even be a flow diversion valve which prevents the forward passage of subtemperature milk. But all these safeguards do not of themselves assure completeness of pasteurization—mechanical devices are subject to breakdown, and plant personnel, either through carelessness, ignorance, or wilfullness, may bring about some failure in the pasteurizing operation.

Health officers and plant control personnel have in recent years been provided with a most valuable tool, in the form of a chemical test, for measuring the efficiency of pasteurization—the phosphatase test. It is based upon the fact that the enzyme, phosphatase, which is present in raw milk, is rendered inactive after milk has been exposed to a temperature of 143° F. for 30 minutes. In making the test, a portion of the milk is added to a substrate containing a phenyl phosphoric ester. The solution is incubated for a short time at body temperature and an indicator is added. If the phosphatase has not been inactivated by the pasteurization process, it causes the liberation of phenol, which forms a dye of blue color by combination with 2, 6-dibromo-quinonechloroimide. The test is sensitive enough to indicate the addition of 0.1% of raw milk to pasteurized milk, a drop of 2° in the pasteurizing temperature, or a shortage of 5 minutes in the holding period.

In well-controlled plants, it is a routine procedure to make a quick phosphatase determination of bottles off the filler line at hourly or even half-hourly intervals. Since lay persons can easily be trained to run the test, there can be no justification for any plant operator putting out milk which has been improperly pasteurized. Although the phosphatase test is indeed a milestone in milk control, it is not in itself a cure-all for plant ills. It is always necessary to maintain adequate supervision over equipment, operation, and personnel.

II. CREAM

Before the introduction of the mechanical cream separator, cream was obtained by permitting milk to stand in vats or pans at room temperature for a period of time long enough for most of the butterfat to rise to the upper portion. The cream layer thus formed was then skimmed off manually by the use of a dipper. This method was, of course, very inefficient in that appreciable quantities of fat were left in the skimmed milk and the resulting product was lacking in both quality and uniformity. The introduction of the mechanical separator (see Fig. 28, page 200) eliminated all these defects and made possible the present highly developed cream, ice-cream, and butter industries.

In order to produce cream of the highest commercial quality, it is necessary that the milk from which it is to be produced be of good market-milk grade. Aside from the butterfat content of cream and an acidity ranging from 0.10 to 0.12% (calculated as lactic acid), the purchaser of cream seeks a rich, sweet, nutlike flavor and a fairly high viscosity.

Most large cream operations are conducted at country plants since it is not commercially feasible to ship the large bulk of water contained in the skimmed milk. In addition, and for the same reason, the manufacture of various by-products from the skimmed milk lends itself better to country operations.

After the milk is dumped and weighed, it is usually heated by means of a surface or internal tubular heater to about 90-100° F. and then run through a mechanical separator. Most efficient separation is obtained within this temperature range. The skimmed milk is run into tanks for eventual use in the manufacture of skimmed condensed milk, skimmed milk powder, buttermilk, or skimmed milk cheese. The cream itself is permitted to flow into the pasteurizing tanks for pasteurization. Spray or coil vats are generally used for this purpose but with a minimum of agitation. The temperature of pasteurization is usually between 145-150° for 30 minutes. The product is then cooled as rapidly as possible to about 38-40°. A surface cooler is customarily employed, but it is frequently the practice to bring about some preliminary cooling in the pasteurization vat by running cold water through the coil or into the jacket in order to prevent the milk proteins from baking onto the coils and walls of the vat. The cream is then filled into forty-quart cans, and aged for about 24 hours. It is then ready for bottling or other commercial use. In connection with the pasteurization of cream, it may be noted that the high-temperature, short-time method has been found feasible and is now used by an ever-growing number of operators.

It may frequently be necessary, in order to meet certain market conditions, for a cream operator to ship raw cream instead of the pasteurized product. One of the difficulties of this practice lies in the fact that an enzyme, lipase, present in raw cream rapidly causes an undesirable oxidized flavor. Heating the milk to about 125° F. prior to separation reduces the activity of this enzyme and prevents the development of such off-flavors.

III. BUTTER

Over one-third of the milk produced in this country is manufactured into butter. While a considerable portion of this butter is farm-made, most of it is the product of commercial creamery operations. Some creameries receive whole milk from producers in more or less close proximity to the plant, but the more common practice is for the manufacturing establishment to receive cream which has been separated on the farm. Large creameries reach out a considerable distance for their supplies, and cream gathering stations are strategically located in dairy sections distant from the creamery. The stations then send their cream into central factories for buttermaking.

Since the quality of the cream has a direct bearing upon the character of the finished butter, creameries carefully grade the cream coming into their plants. Grading is

based upon acidity, flavor, odor, and the presence of foreign substances. It has been shown that a high mold mycelia count in the finished butter never occurs unless it was made from filthy, putrid, or decomposed cream. Where farm cream production is an incidental aspect of the entire farm operation, the producer is not likely to pay too much attention to cream quality. Two or three days' production may be collected before shipment is made to the creamery with the result that only an inferior grade of butter may be made from such cream. Many of the progressive dairy States have inaugurated cream grading laws and are fostering educational campaigns designed to improve cream quality. The Federal Government is also cooperating in these undertakings.

Some butter users require a product made of sweet cream. This is particularly true of ice-cream manufacturers who use butter in their mix; but by far the greatest amount of butter made in this country is from sour cream. Butter made from sweet cream has better keeping qualities at normal storage temperatures. The addition of 10-13% of salt to cream markedly increases the quality of the butter produced. The added salt not only reduces the number of microorganisms which develop in cream but also affects the type of microorganism. It apparently inhibits the development of yeasts and molds and prevents the growth of proteolytic and lipolytic bacteria. The storage of salted cream in ordinary milk cans, however, corrodes the tin. It also has a corrosive action on copper and other dairy metals with the exception of most types of stainless steel.

After the cream is received and blended at the creamery, it is neutralized by the addition of one of the alkaline salts such as sodium bicarbonate, magnesium oxide, or calcium carbonate. See page 413. This is followed by pasteurization or an equivalent heat treatment carried out to enhance the keeping quality of the butter after manufacture. The pasteurized cream is then inoculated with a starter, which is usually a culture of several different types of bacteria producing the souring and volatile flavor factors commonly associated with good butter. The cultured cream is then permitted to ripen at about 70° F. for three or four hours, or until an acidity of 0.3-0.4% is reached, after which it is cooled and run into the churn where color is added if desired. The revolving and agitating action of the churn causes an inversion of the oil-in-water emulsion, with subsequent coalescing of butterfat particles and the formation of granules of butter, after which the buttermilk is permitted to drain off. The physicochemical aspects of churning are discussed in Volume I, page 45. Fresh water for washing the butter is then added to remove the remainder of the buttermilk. After this wash water has been drawn off, salt may be added, and the butter worked until the desired consistency and moisture content are reached. This latter point must, of course, be determined by an analysis, although the experienced buttermaker can pretty nearly tell when the working is completed.

The butter is packed in tubs or boxes, or is mechanically cut and wrapped in pound-size paper cartons for the retail trade. The grading of butter is discussed in Volume I, page 423. The fermentation phases of butter manufacture are discussed on pages 387 *et seq.*

IV. FROZEN DESSERTS

The manufacture of frozen desserts has rapidly evolved from a luxury industry to an important position in the food processing field. Because of the character of many ingredients used in ice-cream manufacture (Fig. 144), and because many of the processing steps are so similar to those encountered in milk processing, it is advisable to apply milk sanitation standards to this industry. Health officials and progressive manufacturers have adopted this policy on an increasingly broader scale.

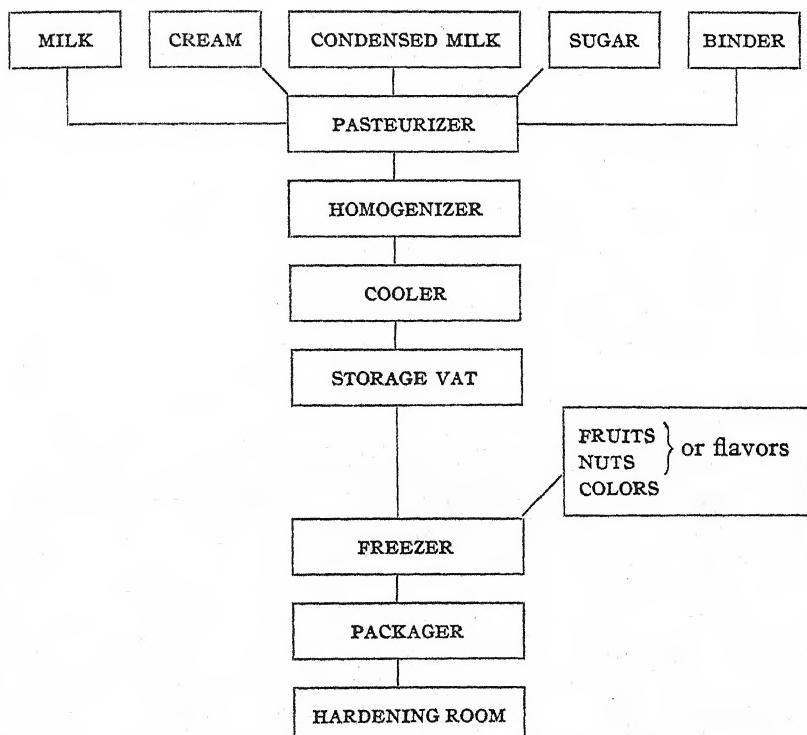


Fig. 144.—The manufacture of ice cream containing milk, cream, condensed milk, sugar, binder, color, and flavor.

The types of milk product ingredients entering into ice-cream mixes vary with the individual manufacturer. The butterfat content may be derived from fresh cream, storage cream, sweet cream butter, or combinations of the three. The source of milk solids is generally dried skimmed milk, condensed milk, or condensed skimmed milk, while the sugar used may be granulated or in sirup form. Any one of a dozen different stabilizers (see page 415) are commonly used. The coloring and flavoring materials cover a very broad range. Commercial ice-cream formulas vary from 8-12% in butterfat, 14-16% in sugar content, and 10-12% in milk serum solids. See Volume I, page 427.

The ingredients (except for fruits and most flavors) are mixed in a heated vat equipped with an agitator. This same vat may also serve as a pasteurizer. The mix is usually pasteurized at 150–155° F., and held at that temperature for 30 minutes. It is then pumped through a homogenizer under 2500–4000 pounds of pressure. The homogenizer serves to make the mix smooth, and breaks the fat globules up into particles small enough to keep them suspended throughout the entire mix mass. The mix is then cooled and pumped into a storage tank to await freezing. Fruits, other flavoring material, and color are added at the freezer.

1. Freezing

Two types of freezers are employed in commercial ice-cream operation: the batch freezer; and the continuous freezer. In both cases, the freezer consists of a double-walled cylinder with ammonia gas or brine circulating between the walls to provide the freezing medium.

The batch freezer is provided with dashers and scrapers revolving on a horizontal axis. As the dashers throw the mix against the cylinder walls, the mix freezes on contact and the blades scrape the partly frozen material back into the chamber. At the same time, the whipping action of the revolving mechanism causes the incorporation of air into the mass, thereby increasing its volume. The increase in volume is termed the overrun. When the overrun reaches the desired volume (90–100%) the batch is ready to be drawn off for packaging.

The continuous freezer differs in principle from the batch freezer chiefly in that it provides for the feeding of fixed quantities of air into the freezing chamber to produce the required overrun. Fresh mix is steadily run into the freezer, and the semisolid ice cream emerges from the freezer outlet in a continuous manner during the entire operation.

2. Packaging

A considerable change in packaging and merchandising of ice cream has taken place in the past decade. Most ice cream was formerly filled into 2½- or 5-gallon metal or paper containers directly from the freezers; but at the present time a large part of the ice cream is produced in novelty forms for individual servings. These forms include ice-cream pops, cups, sandwiches, rolls, etc., and their production usually involves a certain amount of handling, with the attendant danger of contamination.

It is customary to permit the ice cream to run from the freezer into a can and to carry this semisolid mass to a pop mould filling table or cup filling machine. This manual handling, however, may be eliminated by pumping the ice cream from a hopper located in front of the freezer into completely closed filling machines. Positive-type pumps should be used in this operation. Some loss of overrun may be encountered while the pipe lines and hoppers are being chilled to the ice-cream temperature, but this difficulty is largely overcome if the operation is of considerable size and is carried on in a continuous manner.

While the chief reason for conducting filling operations in a completely enclosed

system is to keep potential contamination by human handling to a minimum, many operators have found this procedure economical from a labor-saving standpoint.

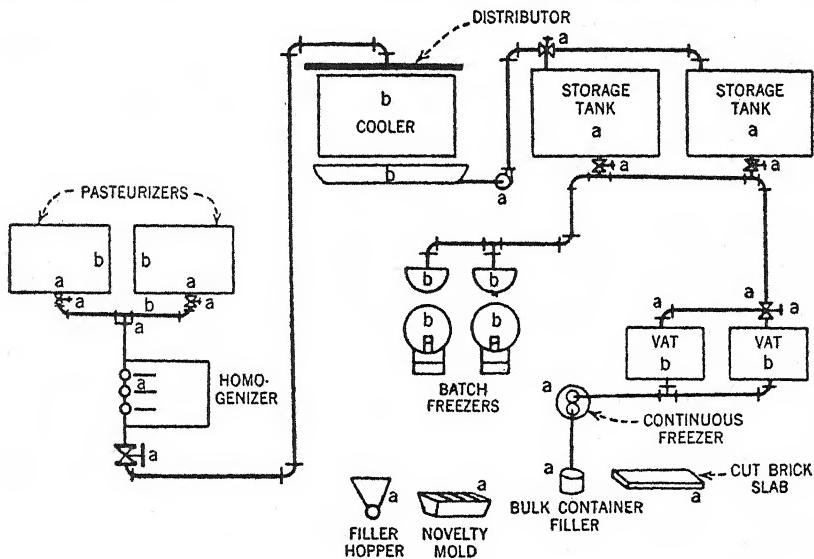


Fig. 145.—Diagram of ice-cream manufacturing. The letters *a* and *b* indicate steps in the sterilizing operation as follows: *a*, immerse parts in sterilizing solution before or during assembly; *b*, spray or flood with sterilizing solution.⁴

3. Hardening

Bulk ice cream, cups, and brick moulds are placed in a hardening room, which is kept at a temperature of -10 to -20° F., immediately after filling. Ice-cream pops, however, are conveyed through a calcium chloride brine tank at a temperature of -10 to -50° . The pops become solidified and are removed by dipping the mould into hot water to loosen them and permit their withdrawal. The pops are then coated with chocolate, coconut shreds, or other flavoring material, and are bagged and placed in the hardening room for storage.

V. CHEESE

As explained in Volume I (page 428), cheese is made by coagulating milk and then modifying or, as it is termed, ripening the coagulated product. It will be useful to describe, of the principal 18 varieties, the manufacture of American Cheddar cheese.

1. Cheddar Cheese

The milk received at the cheese plant is transferred to a rectangular cheese vat. This vat, equipped so that the whey may be drawn off at the bottom, is placed within a second vat so that it can be heated by hot water. After standardization and ad-

⁴ *Food Industries*, 16, No. 3, 89 (1944).

justment of the milk to a known fat concentration, usually 3.25%, the acidity of the milk is determined by titration with 0.1 N alkali solution using phenolphthalein solution as the indicator. Sufficient lactic acid bacteria starter is added to raise the acid concentration of the milk to 0.17–0.2%. The coloring matter to be used is added in the ratio of $\frac{1}{3}$ oz. to 1000 lbs. of milk for a light color and 2 oz. to 1000 lbs. of milk for a dark color. The milk is brought to the required temperature, 84–88° F., by the use of hot water in the outer jacket. Sufficient rennet extract, diluted with water to 20 times its volume, is added to coagulate the milk within about 20 minutes. Usually from 2.5–4 oz. of rennet extract to 1000 lbs. of milk is adequate. The milk is then stirred thoroughly.

The firm curd formed is cut into $\frac{1}{2}$ -in. cubes by cutting the curd lengthwise with a horizontal series of blades or wires set in a frame, and both crosswise and lengthwise with a vertical set of blades or wires. The cut curd is heated slowly by injecting steam into the water in the surrounding tank until the temperature reaches 98–104° F. This takes about 30–40 minutes. The curd is kept from coalescing by gentle agitation with a curd rake. The heating causes a marked contraction of the curd cubes, with a consequent loss of water. After the heating is completed, as determined by the feel and appearance of the curd, a strainer is placed in front of the drawoff outlet and the whey is removed by gravity flow. The curd is piled on the sides of the vat to assist in the draining and matting.

The curd cubes coalesce to form a uniform mass. With a large knife, the mass of curd is cut into blocks, 2–4 in. thick, 8–14 in. long, and 6–10 in. wide. The blocks are rotated every 15 min. and piled 2 to 6 slabs deep. This step is called cheddaring and is performed to permit the curd to mat into one mass. The curd is then passed into a rotatable, hollow cylindrical drum which contains a number of thin blades for cutting the curd into pieces $\frac{1}{2}$ –1 in. wide and 2–3 in. long. More whey is removed in this step. After milling, as this operation is termed, the cut curd is stirred to prevent further matting, and salt is added by sprinkling sodium chloride in the ratio of 1–2.5 lbs. to each 1000 lbs. of the original milk used.

The prepared curd is placed into hoops lined with a cheesecloth bandage and having a starched cheesecloth bottom. When the hoop is filled with the curd, another circle of starched cheesecloth is used as a top cover. A circular wooden block is placed over the top cloth cover and the hoop is then placed into a cheese press. Pressure is gradually increased to pack the curd. This is continued for 24 hrs., after which the hoop is removed to adjust the cheesecloth covering and is replaced for an additional 24 hrs. of pressing. The pressed green cheese is allowed to dry for several days and then is dipped into a molten paraffin bath. The paraffin coating checks further loss of water during curing and the hot material kills any superficial mold.

In order to cure the green cheese, it is placed in a ventilated chamber at 40–65° F., lower temperatures providing a slower cure. The temperature is generally kept below 55°. It is probable that initially bacteria of the *Streptococcus lactis* type predominate and produce sufficient acid to restrict the growth of other bacteria.

The bacteriological aspects of cheese curing are discussed on pages 388 *et seq.*

2. Process Cheese

One of the principal reasons for the large increase in the production and use of process cheese (Fig. 146) is the ability to manufacture a uniform product. Other factors are the ability to make the product in a relatively short time and, when it arises, to supply a given demand. The lack of uniformity in bulk cheese has contributed to the increase in use of process cheese.

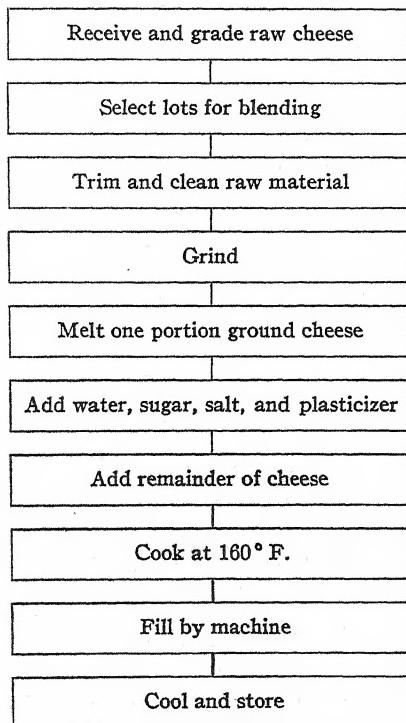


Fig. 146.—Process cheese manufacture.

Two grades of cheese enter into the manufacture of process cheese: green or current cheese, and cured or sharp cheese. It is necessary, in order to produce a uniform product, to vary the ratio of sharp to green cheese to meet flavor requirements. Generally, six cheddars of green cheese are used for each cheddar of sharp American cheese.

The temperature of the cheese to be used should be permitted to rise to 70° F. The cheddars are thoroughly cleaned and trimmed to remove the cheesecloth, paraffin coating, external mold, and discolorations. They are passed through a grinder in which some mixing of the cheese takes place. About one-eighth of the cheese to be processed is transferred to the cooker. The cheese is melted either by the direct injection of steam or by the use of a steam jacket, depending upon the type of cooker.

The water, salt, sugar, and plasticizer required are added and, finally, the remainder of the ground cheese. The amount of water used depends upon the texture desired; the quantity of salt is regulated by the flavor; while the plasticizer or emulsifier such as disodium hydrogen phosphate (page 416), added in the amount of 1-2% of the weight of the cheese used, assists in producing a homogeneous mass.

During the cooking, the temperature of which ranges from 150-170° F. for 10-15 minutes, there is an initial tendency for butterfat to separate; but, as the temperature increases and the mixture is continuously stirred, a homogeneous mass resembling bread dough results. The stirring⁵ incorporates air, producing an increase in volume or overrun. In the cooking step the cheese is pasteurized. The customary finishing temperature is 160°. The hot processed cheese is passed directly from the cooker to the filling machine, where greaseproof wrapper-lined moulds, paper cartons, or wooden boxes are filled and sealed.

There are many variations in the manufacture of process cheese and some of these variations have been patented. Thus, for instance, if sufficient quantity of an edible acid such as lactic, acetic, or propionic acid is added to the drained curd so that the pH is rapidly reduced to 4.8-5.2, then the curd may be processed without further curing. This eliminates the steps of cheddaring, milling, hooping, and bandaging of the cheese. See page 644. The time of manufacture from receipt of whole milk to processed, packaged cheese is reduced to 24 hours or less. In another variation, lipolytic enzymes derived from mammary tissue are added to milk to be used for the manufacture of cheese in order to speed the development of flavor and shorten the ripening period. This improvement in flavor probably results from the destruction by microorganisms of the butyric acid resulting from fat hydrolysis, while higher fatty acids accumulate and contribute to flavor development.

VI. CONDENSED MILK

Milk is condensed by use of vacuum pans which can be operated under 25 in. of vacuum so that the milk boils at 130-135° F. At this temperature, undesirable changes are avoided. The evaporator is generally a copper- or enamel-lined steel cylinder from 3-7 ft. in diameter. The vacuum pan has a concave bottom equipped with a steam jacket. Above the jacket, inside the cylinder, are steam coils which assist in the evaporation.

The milk is placed in a preheater tank and is heated to about 165-185° F. The vacuum pan, heated with steam, is evacuated by means of a pump. Milk is drawn into the pan by this vacuum and, as it covers the bottom jacket, steam is permitted to enter. As the milk rises and covers the coils, steam is turned into the coils. The milk is thrown as a spray into the upper section of the retort by vigorous boiling. This assists in rapid evaporation. When the specific gravity, as determined with a Baumé hydrometer, indicates that the required condensation has been accomplished, the milk is withdrawn and is cooled over surface coolers or in coil vats.

⁵ C. R. Barker, *Food Industries*, 13, No. 12, 53 (1941).

If analysis of this product indicates it fails to comply with the standard of the plant, the milk is standardized by adjusting the ratio of fat to solids-not-fat by addition of

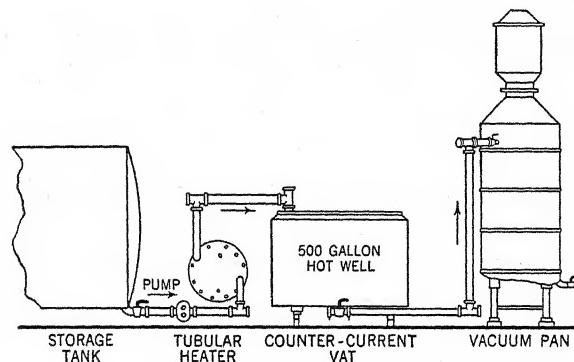


Fig. 147a.—Condensing unit used in evaporated milk plants. Milk is pumped through the heater and into the hot well from which it is then drawn into the vacuum pan. (Courtesy Mojonnier Bros. Co., Chicago, Ill.)

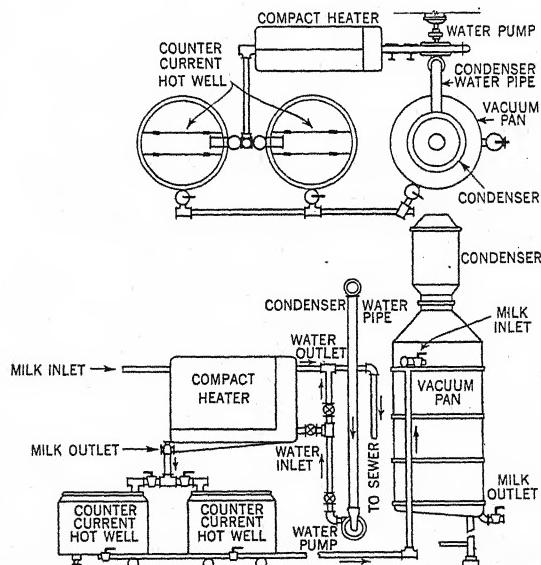


Fig. 147b.—Condensing unit illustrating the use of waste condensing water for preheating milk ahead of the hot wells where the balance of the heating is performed. (Courtesy Mojonnier Bros. Co., Chicago, Ill.)

the necessary components, either butterfat or milk solids-not-fat, as the case may be. Evaporated milk is then homogenized and cooled, and put into containers and sterilized.

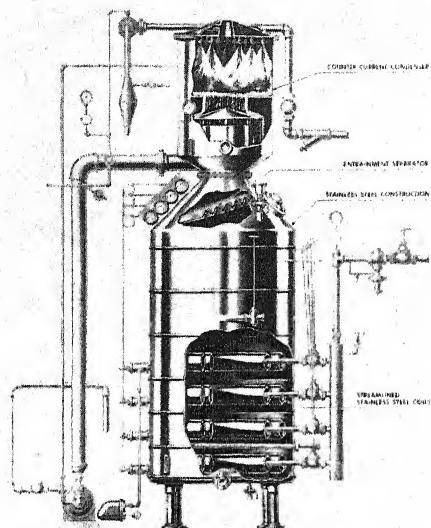


Fig. 147c.—Diagram of milk condensing equipment. Stainless-steel vacuum pan. (Courtesy Mojonnier Bros. Co., Chicago, Ill.)

Sweetened condensed milk is manufactured in a similar manner except that it must be standardized before evaporation. It must also be cooled quickly with agitation.

VII. OTHER MILK PRODUCTS

This chapter has been written in close connection with the chapter on the descriptive aspects of milk and milk products in Volume I, page 395 *et seq.*

The manufacture of other types of milk products has been discussed in other sections of the text. The production of dried whole milk and skim milk powder has been described as a phase of food preservation by dehydration. See page 304. The manufacture of cultured sour cream and cultured buttermilk has been given in connection with the description of their composition (Volume I, pages 421 and 431).

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Chapter XXI

MEAT AND MEAT PRODUCTS

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I. HANDLING OF ANIMALS PRIOR TO SLAUGHTER

The producer of meat animals completes his contribution to the production of food at the time the animals start to market. From this point on two objectives are sought: to transport the animals to the meat-packing establishment in as near the same condition as they are at the start of the journey; and, upon their arrival at the meat-packing establishment, to process them into food and a variety of by-products.

The transportation of animals to the meat-packing establishment exposes them to a change in environment and frequently to unusual exertions and excitement. Great care must be exercised in protecting the animals against these new conditions in order to avoid losses or lowering of the quality of meat obtained from them. Animals which have received good care and are well rested and fed at the time they are dispatched usually produce meat of higher grade.

Livestock losses occur during shipment from the farm to public stockyards, handling in the stockyards, and handling by the meat packers. Each species of animal has its own characteristic weaknesses; and, while certain general statements apply to all animals, others pertain only to specific species. It is a general rule that all animals should be handled with a minimum of exertion; in the case of hogs this is particularly true. In their normal life, pen-fed hogs do not have the opportunity for much exercise. As a consequence, their lungs, unaccustomed to supplying comparatively large quantities of oxygen, fail to develop to the fullest extent. When the hogs are subjected to the unusual exertions associated with transportation to the market, the strain on the vital organs is abnormal; unless the animals are given opportunity to rest, they may not survive.

The following relatively brief description may be made on methods of handling the four main species of livestock.

1. Shipping

Livestock may be shipped by railroad or truck. Loading of railroad cars occurs at some point, to which the animals may be driven or carried by truck or other conveyance. Animals are usually given a rest, and may be watered and fed, prior to loading.

Care must be exercised to avoid overfeeding and watering of hogs in order to avoid interference with respiration. The conveyances, whether railroad car or truck, must be clean and in good condition. Anything which will bruise or injure the animals must be removed. Crowding is avoided; and if animals of more than one kind are placed in a car, a suitable separation is provided. A bedding of sand or of sand and straw is usually provided. According to federal law, in long interstate hauls, animals must be removed from the carrier conveyance and watered and fed every 28 hours (except on the last haul, when it may be 36 hours). At the request of the owner, the normal period of 28 hours may be extended to 36.

2. Public Stockyards Handling

The distance livestock must be driven is held to a minimum. Pens are usually made of a size to handle the separate lots of livestock received, although this is not always possible. Pens for cattle and calves are usually open. Those for hogs and sheep are provided with a cover. Ample ventilation, however, is afforded. Floors are usually of brick or concrete, are sloped to a drain, and are roughened to prevent slipping by the animals. Normally each pen is equipped with a water trough and feed container. Water troughs of hog pens are designed to prevent hogs from wallowing in them.

Upon arrival at the public stockyards, the livestock are unloaded, counted, and assigned to pens. They are then fed, watered, and bedded down. When sold, they are weighed, and held subject to disposal by the buyer.

3. Handling in the Meat-Packing Plant

Nearly all meat-packing plants have a small stockyard adjacent to the plant for holding the animals. In general, these storage facilities are modeled after those of public stockyards. All animals are usually rested overnight before processing begins. Hogs particularly are given an opportunity for rest immediately beforehand.

Feed and water are usually provided, although cattle should not be fed excessively immediately before they go to the dressing floor. Cattle, hogs, and calves are usually driven to this floor. Frequently an electric prod is used to keep the animals moving. Animals touched with this prod are given a light harmless shock. Bruising of animals in any way is avoided, since this lowers the quality of the meat obtained from the carcass and may result in heavy losses. Calves and sheep especially, are protected from dirt; in the case of calves, this is done because the carcass is usually sold with the skin on, although recently other methods of protecting the carcass have been devised; in the case of sheep and lambs, dirt on the wool reduces its value.

II. DISPATCHING OF LIVESTOCK; DRESSING AND CUTTING OF CARCASSES

The techniques of dispatching and dressing vary with the kind of animal.

1. Beef Operations

(a) Slaughtering and Dressing

Two methods are practiced on cattle: the regular method involving stunning of the animals; and the kosher method.

Regular Method.—Since it is difficult to shackle and "stick" cattle, as is done with hogs, it is common practice now to stun the animals to insensibility and to "stick" them while they are insensible. In accomplishing this, the cattle are driven into small pens and a man standing on a platform about on a level with the animal's back hits it on the head over the brain with a 4- to 5-pound hammer. Such a blow causes insensibility. This operation requires considerable skill, for if the blow is too hard it will destroy the skull bones and lessen the value of the brain, and may affect the bleeding later. If the blow is too light, it will not stun the animal.

After the animal is stunned and drops to the floor of the knocking pen, the door of the pen is raised and the floor automatically inclined sufficiently so that the animal is discharged to the dressing floor. A chain is passed around both hind feet just above the ankle joint and the animal is hoisted by means of this chain and hung from a rail support above, placing it in a position for sticking and bleeding. The insensible animal then travels to the sticking point. A knife is inserted through the median line of the neck where it joins the torso and pointed upward and through the front wall of the jugular vein. The animal is allowed to hang until properly bled.

Cattle are such large animals that they do not adapt themselves to a process of dressing involving traveling of the carcasses on a conveyor belt. There is, therefore, much manipulation of the carcass in a given position to permit skinning and dressing.

The head is first skinned and is cut free from the carcass, but is left hanging by the trachea and the esophagus in order to keep the head identified with the carcass. The trachea and esophagus are usually tied, so that the contents of the paunch will not contaminate the carcass.

After the head is removed, the carcass is lowered so that it lies upon its back. The feet are skinned and removed at the knee joint. A cut is made on a straight line through to the median line of the crotch. The trachea and esophagus are loosened from their natural attachments. The skin is cut away from both sides of this incision. Next the breast bone is sawed, as is the aitch bone. The gam cords (on the hind legs) are opened, hooks are inserted, and the carcass elevated to a position known as half hoist. The hide is pulled from the hind shanks and skinning is continued along both legs to the hip bone. A cut is made around the bung to permit the tail to be slit down its entire length so that skin may be removed. The aitch bone is sawed, and the carcass which is now entirely opened, is raised completely to the dressing rail for further dressing. The hide is pulled away from the rest of the back and the neck skinned. The hide is dropped on the floor where it is spread out and inspected preparatory to grading and removal to the hide cellar.

The viscera are dropped into a truck or rolling table directly below the carcass for inspection by the Bureau of Animal Industry. The carcass is split in half by chopping

and sawing through the exact middle of the vertebrae. The tail, spinal cord, and sweetbread are removed and the carcass trimmed.

The carcasses are then washed with water and cloths inserted into the large blood vessels to prevent dripping. The carcass is now ready for the chill rooms, providing it has passed the B. A. I. inspection.

Chilling of the beef carcasses is usually accomplished within 48 hours. It is now well recognized that the quicker the chilling, the less is the danger of spoilage.

Kosher Method.—Kosher dispatching and dressing of cattle, calves, and sheep, as well as chilling of the beef, lamb, and veal, is governed by certain principles of religious significance and is therefore different in several ways from the methods used by the non-Jewish people. In the kosher method, the animals are not stunned but are shackled and hoisted while fully conscious. They are then slowly lowered until one shoulder rests upon the floor. A muzzle is placed over the snout and jaws permitting the neck to be drawn taut and exposing the throat to the cutter. The cutter then skillfully cuts the throat from ear to ear with a special knife and the animal is hoisted to the rail and allowed to bleed fully.

Kosher handling of the carcass subsequent to bleeding is essentially the same as in ordinary methods. The kosher cutter or searcher examines the animal for adhesions or growths when the breast is opened, and again after evisceration. The lungs, liver, heart, and melt are further examined and identified as kosher. The hind quarter is not used by the kosher trade, not because its use is prohibited, but because of difficulties of removing the vascular tissue, the consumption of which is prohibited by the Jewish religion. All arteries and veins are removed from the fore quarters by the retail dealer before cutting them for trade. The kosher regulations require rapid handling of beef, so that the carcasses may be delivered to the retail shops within 24 hours; consequently, rapid chilling is employed.

The above description of the kosher method actually is only the barest outline of the process. There are a great many details of the rabbinical code, such as length of the knife used in slaughter, its sharpness, freedom from the minutest flaw, method of cutting, etc., which are not covered here.

(b) Beef Cutting

Beef cutting is divided into two separate and distinct operations. The applicability of either operation depends entirely upon the quality of the beef. High-quality beef finds its best market as fresh beef, ultimately in the form of retail cuts. The degree to which a meat-packing establishment "breaks down" a high-quality carcass depends to some extent upon its policy and trade outlets. In some few instances, beef may leave the meat plant as sides, but more often as quarters, or in the form of wholesale cuts. Normally the cutting required to produce the retail cuts is done by the retail meat dealer.

Lower quality beef commonly is termed "cutter" or "canner" beef, but more properly should be called "leans," since such beef is produced from cattle which are mar-

keted in an unfattened state. Usually it cannot be marketed as fresh beef in the form of retail cuts. These beef carcasses are separated into the primal parts at the packing plant and in addition are boned. The boneless cuts are used either in sausage or canned meats or as dried and smoked beef, or are cured.

This account will discuss in detail only the cutting operations required to reduce the carcasses to the primal parts. The retail cuts ultimately obtained will be listed, and reference should be made to Fig. 148 for the location of each cut on the carcass.

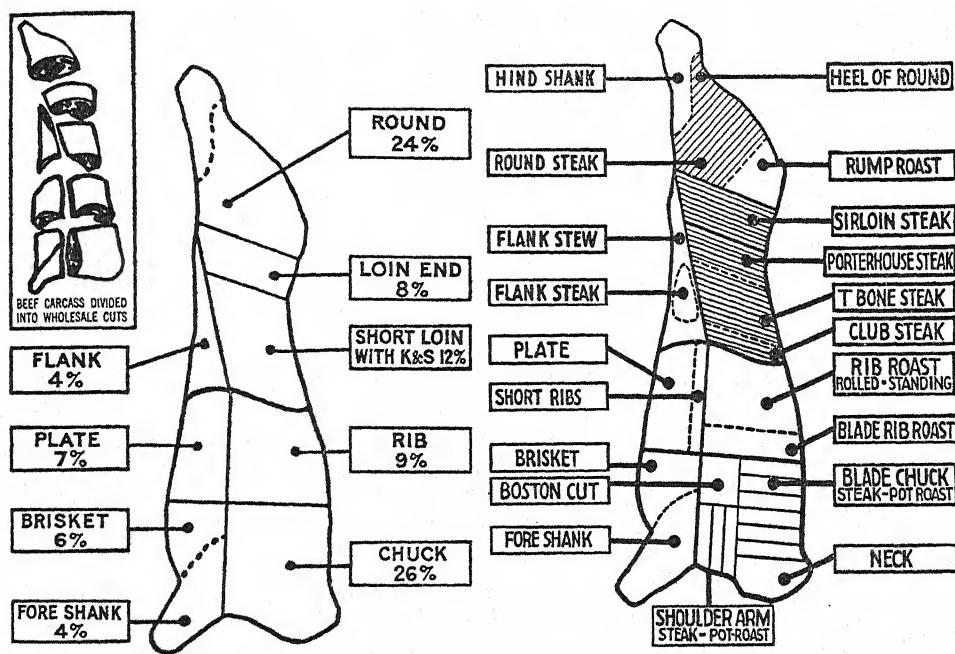


Fig. 148.—Beef charts. Left: wholesale cuts; right: retail cuts.¹

After chilling, the first operation, while the carcass is still hanging, is to quarter it, that is, to halve each side, the cut generally being made so as to leave one rib on the hind quarter. Reduction of the fore quarter to the primal parts is accomplished as follows. The chuck and rib are sawed from the full plate and then the rib is separated from the chuck. The full plate may be divided into the short plate, brisket, and shank. In reducing the hind quarter to its primal parts, the hanging tenderloin, together with the kidney and kidney fat, is first removed. Next the flank is taken off, the remainder being cut into two pieces making a loin and a round with rump attached; the round and the rump are then separated.

The retail cuts obtained from the above primal parts may be described as follows:

¹ National Livestock and Meat Board, *Meat Charts*. Chicago, 1935. The beef chart is slightly modified.

Hind quarter:

(a) Primal part the *round*, comprising about 24% of the side, includes the inside and outside knuckle, shank, and rump. Retail cuts from the round are round steak, rump roast, and shank (soup meat and bone).

(b) Primal part the *loin end*, comprising about 8% of the side, is the piece adjacent to and parallel with the round. The retail cuts of sirloin steak and sirloin roast are obtained from this part.

(c) Primal part the *short loin*, comprising about 8% (plus 4% kidney and suet) of the side is the back side of the hind quarter next to the point of division of the side into quarters. For retail trade, the short loin is cut into porterhouse, T-bone, and club steaks.

(d) Primal part the *flank*, consisting of about 4% of the side, is a triangular piece along the front of the side and in front of the loin end and short loin. Flank steak or flank roll and stew meat are the retail cuts obtained from this primal part.

Fore quarter:

(a) Primal part the *shank* or fore legs to the knee comprises about 4% of the side and is used as soup bone and soup meat.

(b) Primal part the *chuck* extends above the shank along the back side of the carcass and includes the neck. It comprises about 26% of the side. For retail trade, the chuck is cut into chuck pot roast, chuck steak or chuck roll, and chuck roast.

(c) Primal part the *rib* comprises about 9% of the side and takes in that part of the quarter extending from the chuck along the back to the point of division of the side. The rib in retail trade is cut into standing rib roast and rib steaks.

(d) Primal part the *plate* comprises 7% of the side and is located on the front of the side from the point of division into quarters to the brisket. Retail cuts obtained from the plate are short ribs and navel end.

(e) Primal part the *brisket* comprises 6% of the side and is located on the front of the side between the fore shank and the plate. It is used for boiling beef or cured for corned beef.

2. Pork Operations

(a) Dispatching and Dressing

Hogs are held in a pen for rest prior to being dispatched, and are then admitted to a shackling pen. This pen is long and narrow. On one side of the pen is a hoist to which the hogs are individually shackled by a hind leg. This hoist is frequently a large wheel, 12 to 15 feet in diameter. Attached to the circumference of the wheel are a number of short lengths of chain. As the wheel slowly revolves, the shackles which have been looped around the hind leg of the hogs are hooked to these chains, and the hogs are slowly hoisted and hung upon a rail.

The shackled hogs are carried to the "sticker," who plunges a two-edged knife into the center of the neck just below the breast bone about one inch anterior to the sternum (breast bone). The point of the knife is directed upward about 45° in order to sever the jugular vein in the exact center and also to sever the artery located at this point. This makes a smooth opening about one inch long which permits the blood to flow freely. The hog is then permitted to hang from 6 to 10 minutes on the rail to complete the bleeding. When the hog is properly bled, the muscles become limp.

Following the completion of bleeding, the hogs are dropped into a scalding tub. The purpose of scalding is to loosen the hair for easy removal. This tub contains hot

water, the temperature of which is governed to a large degree by the time the hog is to be left in it. In general, temperatures between 55.6 and 61.1° C. are employed. The time required also varies according to the location of the plant, season of the year, and breed of hogs. Approximately 6 minutes is an average time for scalding. Soft water does a better job than hard water.

After scalding the proper time, the hog is removed from the tub and conveyed to the dehairing machine. There are various types of machines, but the essential principle of all is the transporting of the hogs past a series of moving, flexible rubber or canvas belts or beaters, upon the ends of which are fastened small pieces of metal or clips, approximately 2.5 inches wide and 3 inches long. The ends of these clips are slightly curved for scraping the hair from the hog. The hog is sprayed continuously with hot water as it passes through the dehairer.

Upon leaving the dehairing machine, a slit is made in each hind leg of the hog, which exposes the gam cords, so that a gambrel stick may be inserted through both legs and in this manner the hog may be hung, head down, for further operations.

The hogs are next singed. This is done to remove any fine, light-colored hair which the dehairing machine does not remove. There is also a certain amount of hair left on the head and other inaccessible parts. Where hogs of uniform size are killed burners are built to fit the shape of the hog passing through. These burners can be constructed to be adjustable to hogs of different sizes. Hand torches are also employed. Sometimes the hair not removed in the dehairing machine is removed by applying a mixture of rosin and oil to the hog, which quickly solidifies and, when removed, takes with it the hair.

Finally, any hair remaining after the above processes are completed is removed by shaving. Workmen with sharp knives shave all visible hairs. This operation requires considerable dexterity.

At this point the carcass is washed thoroughly to remove all loose hair.

The head is next removed. A knife is inserted in the joint from behind and is worked both ways over the soft bottom of the vertebrae at the point of the neck; the head is then dropped down from the jowl on both sides. The head is left attached to the carcass by means of a very small strip of skin, so that the Bureau of Animal Industry inspectors may inspect the head on the body.

The next operation is the opening of the carcass. Carcasses are opened in the center of the belly. The aitch bone is cut at this time, as is the breast bone. This latter may be cut with a special knife and mallet or with a circular saw. After the hogs are opened, the sides are hooked to those of the adjacent hogs. This process aids in evisceration.

The bung is next cut free and tied. The workman then holds the viscera near the point where they are attached to the vertebrae with hanging tender muscles, and with one cut severs these muscles. With another cut to the left and one to the right he severs the diaphragm which holds the viscera to the ribs. These three cuts loosen the viscera, with the exception of the gullet, from the carcass. The gullet is removed by an additional cut, and the entire viscera are dropped on a table for examination by

the B. A. I. inspector. The viscera include liver, heart, lungs, large and small intestines, pancreas, spleen, stomach, bladder, and fat coverings or the fat in which the organs are imbedded. The kidneys, embedded in a pocket of leaf fat, are pressed upward and outward and left hanging by the "cord" until passed by the B. A. I. inspector. They are then carefully removed.

After evisceration, the carcasses are split down the exact center of the back. A chopper with a wide blade is used. The leaf lard, which hangs in the flank of the hog on both sides, is removed next. Care is taken to remove the leaf all in one piece. The hams are "faced" at this point in order to provide a more pleasing appearance when they are completely processed. The carcass is given a final wash. Usually it is then weighed and branded on each of the primal parts with the legend, "U. S. Inspected and Passed," and the establishment number. The carcass is then ready for the cooler. Carcasses are separated according to weight, and the same weights placed together. This makes it more convenient for chilling and for cutting similar weights and grades later on.

Chilling is one of the most important operations in the steps of processing pork. The most important consideration after the carcass is dressed is to reduce the temperature as quickly as possible to a point at which bacterial growth will be greatly retarded. Efforts are now directed to obtain chilling of hog carcasses in 18 to 24 hours. A hog with a bone temperature of 0 to 2.2° C. is considered chilled. Hogs shrink in weight upon being chilled. The amount of shrink is a variable quantity, and depends upon such conditions as the dryness of the hogs, the air circulation in the chill room, and the temperature and humidity of the air. An average shrink in 48 hours may be 2.5%.

(b) Pork Cutting

After the hog carcasses are chilled, they are distributed through one of several channels. The uses to which a hog carcass may be put vary to some extent upon the classification of the carcass. The classes generally recognized are: loin hogs; shipper hogs and pigs; bacon hogs; and lard hogs. Loin hogs are generally cut into wholesale cuts at the meat-packing plant, and must meet requirements as to finish as indicated by the depth and evenness of fat covering and the amount and quality of the leaf fat. Such hogs should have well-filled hams and shoulders and reasonable length. Weight is also important. Shipper hogs are similar to loin hogs, but are generally lighter in weight and not so highly finished. Shipper hogs are the carcasses of light young swine. Bacon hogs are suitable primarily for English meats, principally for Wiltshire sides. Wiltshire sides ordinarily are not an important item in the United States, but the war has increased the demand for this pork product for export to England. In bacon hogs, length of side is more important, and the covering of fat over the entire carcass should be light and uniform. Lard hogs are heavy, exceptionally well-finished types, which yield a large percentage of lard.

The grading of pork cuts is more complex than that of other meats, since it involves

not only the ordinary factors of quality (*e.g.*, proportions of fat and lean, weight, etc.), but also the styles of cutting and methods of packing by which they are prepared for different classes of trade. No attempt will be made here to describe the various types of grades of cuts. Such detail is not essential to the understanding of meat-packing operations.

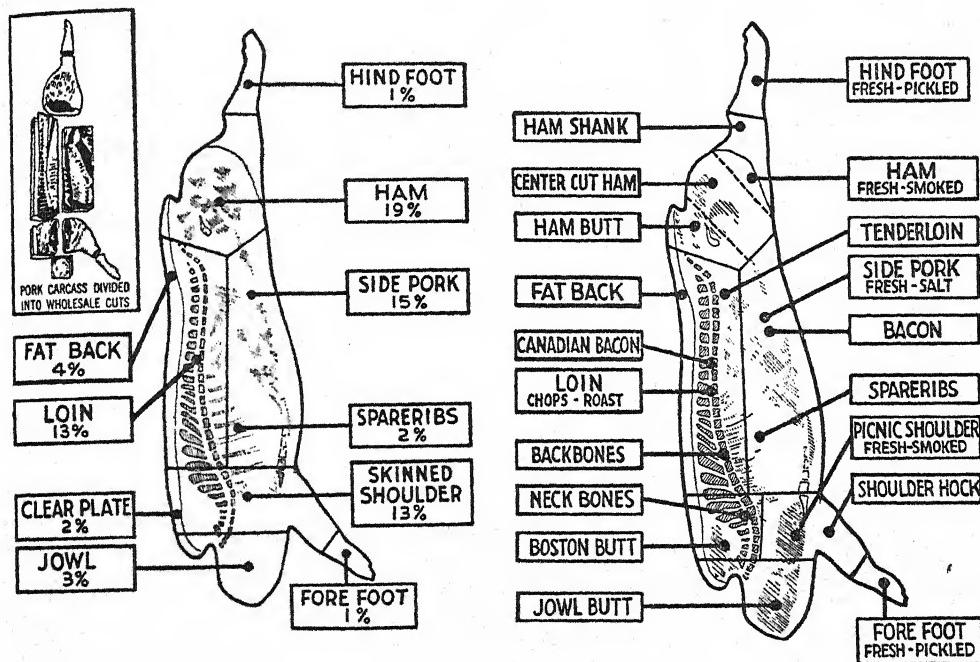


Fig. 149.—Pork charts. Left: wholesale cuts; right: retail cuts.⁴

The temperature at which hogs are brought out after being chilled varies with individual plant practice. It may range from 0 to 3.3° C. These temperatures are sufficient to arrest bacterial development and harden the meat for easy and accurate cutting. Knives used in cutting are dipped in hot water immediately prior to use in order to facilitate cutting, especially through hard chilled fat.

A modern pork-cutting floor is well designed, and makes use of many mechanical devices to accomplish the cutting operations efficiently and rapidly. No standard design of cutting floor can be given; but, in general, certain essential features are present for performing the various fairly standardized operations. The hogs are usually brought from the cooler by a conveyor, and are dropped on a moving table by cutting the gam strings. The moving table conveys the hog past an operator who saws the bone with a mechanically driven saw, permitting the ham to be cut off. The ham is

⁴ National Livestock and Meat Board, *Meat Charts*. Chicago, 1935.

slid to a band saw, where the foot is cut off. The rest of the carcass proceeds to the second station, where the shoulder is chopped off. In some instances a circular knife rather than a chopper is employed for this operation. After the shoulders are cut off, they are conveyed to a band saw which cuts off the feet and butt. Neck bones are next lifted, and the neck is trimmed. The butt is removed from the shoulder. The picnic or shoulder ham is then cut out, followed by the jowls. After this, a cut is made through the ribs the entire length of the side on a line from the inside edge of the tail bone to the inside tip of the back bone on the shoulder end. This permits easier loin pulling, which is the next operation. Loins are pulled by drawing a two-handled knife through the side between the loin and the fat.

After the sides have been passed through a roller to press them flat, they are ribbed. The fat back is removed from the belly, either mechanically or by hand. The bellies are trimmed to size and are subsequently converted to bacon through curing and smoking. The fat backs, if intended for the manufacture of lard, may be skinned. Frequently, bellies are skinned prior to curing.

Following the pork-cutting operations, some cuts require additional trimming, in accordance with the use for which they are intended. Hams are frequently partially skinned and boned. Loins are frequently boned, and many of the cuts receive additional trimming. The small pieces of meat obtained in this way are utilized in the manufacture of sausage and other table-ready meats. Reference should be made to Fig. 149 depicting the principal wholesale and retail cuts.

Specialty pork items are usually handled separately, and include tongues, brains chitterlings (intestines), spleens, plucks (liver and heart), giblet meat (fleshy portion of the diaphragm muscle), kidneys, pigs' feet, and pigtails.

3. Lamb Operations

The processing of lamb is somewhat simplified because of the smaller size of the animals. At present, most sheep-slaughtering plants now employ a wheel hoist similar to that used in the dispatching of hogs. A double shackle in which the two shackles are attached to a steel "spreader bar" is employed instead of the single hog shackle. This steel bar is attached to a chain on the wheel hoist which raises the animals and drops them on a bleeding rail. Particular attention is paid to the application of the shackle at a point just above the toes in order to avoid an unsightly scored appearance of the hind leg, since the hind leg of the animal is one of its most valuable parts. In dispatching sheep, a very sharp, pointed knife shaped like a dagger is inserted into the neck just below the ear so that it severs the jugular vein and other blood vessels in the neck. The animal is allowed to bleed about 6 minutes before the second operation, skinning, is undertaken.

The first step in the dressing of the carcass is that of leg breaking, and involves a process of breaking the joints of the fore leg just above the feet. In the case of lambs, which do not have a complete knuckle developed, the joints break off, carrying the undeveloped knuckle with them. Sheep, on the other hand, have a fully developed

knuckle, and the joints break, leaving the knuckle on the carcass. Following breaking, the feet are removed from the carcass. The skinning operation is started on the right hind leg. In doing this, the operator makes a vertical slit at the hock, care being taken not to damage the carcass. With this opening made, the operator clears the skin away first from one hind leg and then from the other. The fore quarter is next raised by attaching a metal triangular spreader to the fore leg just above the toes, the spreader being attached to a trolley which rides along a track running parallel to the

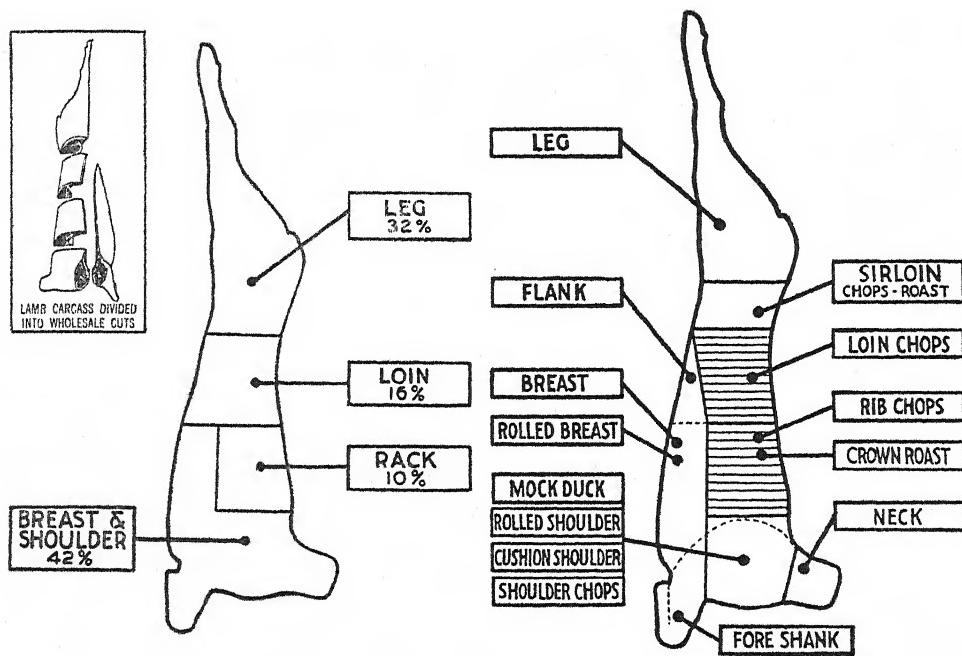


Fig. 150.—Lamb charts. Left: wholesale cuts; right: retail cuts.²

track to which the hind legs are attached; and an incision is made with a broad knife about the middle of the breast. The skin is cut down to the head exactly in the center of the neck and is cleared back a short way on each side. The skin is removed from the legs starting on the inside of each leg. Next the skin is pulled from the breast and then from both sides of the head. At this time the weasand is disengaged and tied. The fore quarters then are let down and the spreader removed. A cut is made in the skin from the crotch down to the breast opening, cutting in the exact center of the belly. The skin is forced away from the carcass as far as possible, and a cut is made on one side of the tail, which permits clearing the skin away from the rump and a part of the hind quarter. The skin is pulled away from the back and cut loose from the neck and head. After removal of the pelt, the carcass is washed on the outside with slightly warm water.

The first dressing operation after skinning consists of opening the breast, and is accomplished by the use of a very heavy sharp knife. This is pressed along the breast in a vertical position, and is driven in by striking the back of the knife with a wooden mallet. The next operation is opening the carcass down the front with a very sharp knife, the incision being made from the breast slit down to the crotch. Inspection of the viscera by the Bureau of Animal Industry (see page 110) usually occurs at this point. The caul fat is removed next, for transfer to the oleo department. The bung, including the entire group of small intestines, is removed, and following this, the paunch. The pluck consists of lungs, liver, and heart, and is taken out next. At this point, a small wooden stick about 8 inches long is inserted in the belly of the carcass in order to spread it apart and thus to assist in chilling. The legs are then crossed, both legs are hung on one hook, and the legs are tied for easy handling.

The next operation is that of cutting off the head. The inside of the carcass is then washed with water and dried. Some trimming of the carcass is done in order to improve its appearance. In some cases, a steel neck pin about 8 inches long is inserted in the neck into the breast. This straightens the neck and avoids damage to the carcass in the subsequent handling. The fore legs are folded back in the joint, and a skewer is inserted in the back joining the front of the fore legs and fastening them together. This improves the appearance of the carcass and saves space in handling. The carcasses are next transferred to the chill room, and, when in place, the neck pins are removed. The temperature is maintained just above 0° C. Complete chilling seldom takes more than 24 hours because of the smallness of lamb and sheep carcasses.

Lamb is marketed as a whole carcass or may be divided before delivery to the retailer. Reference should be made to Fig. 150 for the cuts obtained from lamb and sheep carcasses.

4. Calf Operations

Calves for meat processing are considered to be largely a by-product of the dairy industry. In order to keep cows producing milk, they must be bred to produce calves at regular intervals. It is generally believed that the raising of such surplus calves is not economical. While not always done it is rather common practice to sell calf carcasses to the retailer with the skin on. Hence, in handling the live calves, great care is taken to keep the animals clean. In some cases, provision is made to bathe the animals before they are processed.

The method of handling calves is not uniform. Some plants stun the calves before sticking, and others shackle and stick without stunning. Calves are shackled very much as are sheep. A wheel hoist similar to that used for hogs and sheep is employed; but because of the light weight of the animals, two calves are shackled on a single shackle and are hoisted simultaneously and dropped upon the bleeding rail.

Ordinarily, the sticking is done by a dagger-shaped, sharp, pointed knife. The incision is made at a point in the right side of the neck below the jaw. The jugular vein and other blood vessels of the neck are severed. The animals are allowed to hang until bled fully.

The calf skin is washed in the next operation. There are various ways of accomplishing this. In smaller establishments, hand washing with fountain brushes is practiced. Where larger numbers of calves are handled, mechanical washers are employed, using water under high pressure and revolving brushes. Federal inspection does not permit calves with dirty hides to be dressed. The first operation of dressing is the skinning of the head. Then the legs, both front and rear, are skinned and removed at the knee joint. The breast is opened next by applying a sharp, heavy knife to the cen-

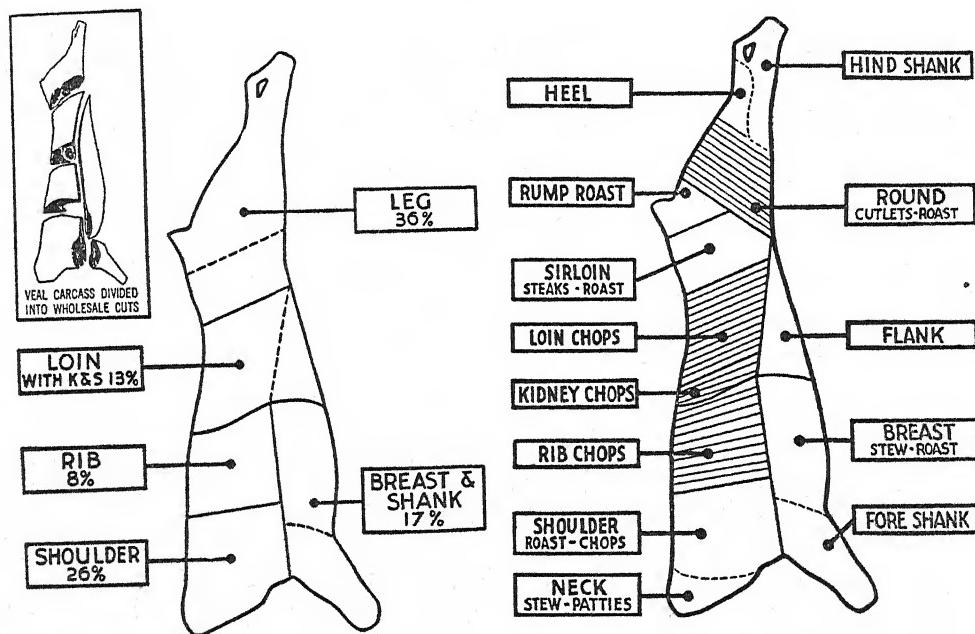


Fig. 151.—Veal charts. Left: wholesale cuts; right: retail cuts.²

ter of the breast and driving it through with a wooden mallet. The head is removed at this point. The opening of the animal is completed by cutting down with a sharp knife from the crotch to the opening made in the breast, cutting through the flesh and severing the aitch bone. The caul fat is removed next, and the bladder disconnected. The middle intestines and bungs are removed, followed by the small intestines and the paunch. The pluck, including the liver, lungs, and heart, is carefully removed, since it is a valuable item.

The gam holes are marked and the calf hung on a trolley much in the way a dressed hog carcass is. The inside of the carcass is then washed; and it is ready for chilling. Because of their small size, calves can be thoroughly chilled quickly so that they can be ready for shipment within 24 hours.

The practice described is not uniform. In some instances, calves may be skinned

warm and a protective coating applied to replace the skin. Skinning of the chilled carcass is also practiced to some extent, but is a rather difficult operation. Since the young animals are not protected by the layer of fat one usually finds in the mature animals, calf carcasses need a protective coating. Because this fat layer is not present, the flesh surface dries out and the meat loses its normal natural appearance. In an effort to keep the meat from drying out or darkening, veal has commonly been shipped hide on or wrapped in a stockinet. Neither method has proved really satisfactory. An improved method of shipping veal has been worked out in the "Saniseal" process.³ The Saniseal-Wrapped process affords the protection of three wrappers, a glovetight covering of special cloth, a white parchment, and finally a stockinet. These wrappers effectively prevent drying and darkening.

Reference should be made to Fig. 151 for the location of the various retail veal cuts obtained from a calf carcass.

III. FANCY MEATS

Included under this term are head meats, sweetbread, tongue, heart, liver, spleen (melts), tripe, kidney, oxtail, pigtail, and many other items of a similar nature. As a class, although it does not apply to certain individuals of the group, these items may be described as organ rather than muscle meat. In the early days of meat packing, such products were drugs on the market and presented a serious problem of disposal. With the recognition that their nutritional value is exceptionally high, the position of many of the items, such as liver, for example, in the meat-packing business has been altered. Today, the proper processing and marketing of these "fancy meats," as they are termed, constitute an important part of the meat packers' operations.

To a degree, fancy meat products are even more perishable and require more attention than regular meat products. The production of these items, partly because of their perishable nature, is intimately associated with the operations immediately following the dispatching of the animal. In general, these products are removed either on the dressing floor or in special departments such as the head trimming department or in the viscera separating department.

Following are the operations by which the more important fancy meats are obtained.

1. Head Meats

Hog heads are processed immediately after removal from the carcass on the killing floor. Heads which are not to be marketed as the whole head are cut into skull fat for lard; ears, snouts, lips, and tongue for sausage or for curing; cheek meat, head and jaw meat for sausage; brains for sale fresh or frozen; and jaws and skulls for lard, grease, and glue.

Beef heads are cut free from the carcass and pass a rigid inspection by the B. A. I. inspector. After this the tongues are removed. Head meat is removed principally

³ B. E. Williams and L. L. Cadwell, "Treatment of Calves", U. S. Patent 2,076,053, 1937.

for use in sausage and other table-ready meats. Cheek meat is next cut off, and may be used fresh or cured for sausage or sold to retail markets or to canners. The head is then split and the brains removed and washed.

Sheep heads after removal from the carcass are washed, and the tongues removed. Cheek meat is trimmed off. Any other meat present on the head is removed. The head is then split and the brains removed. The remainder of the head is sent to the tanks either for tallow and glue or tallow and bone meal.

Unless the calf heads are chilled and sold as such, they are thoroughly washed after skinning, the tongues removed, and the cheek and other meat trimmed out. The skulls are split and the brains removed. The remainder of the head is disposed of in departments treating inedibles.

2. Livers

Hog livers are removed with the pluck (trachea, esophagus, liver, heart, and lungs). The livers, after B. A. I. inspection, are hung on tinned hooks or racks and rapidly chilled. Beef livers are removed from the carcass after the small intestines have been taken out. They are removed by the operator who attends to the eviscerating of the cattle on the killing floor. Generally, beef livers are cut across the thin border or lower extremity of the liver so that, when hung, any excess blood drains out. Sheep livers are removed with the pluck. The livers are carefully trimmed and washed and hung upon racks for chilling. Calf livers are also removed with plucks and are especially prized.

3. Plucks

The hog pluck consists of trachea, esophagus, liver, heart, and lungs, and is separated from the rest of the viscera after removal from the hog. The gall bladder, liver, heart, lungs, and gullet meat are trimmed off in succession and separated. The gall or gall bladder may be used for the manufacture of pharmaceutical supplies; the trachea (wind pipe) may be used for rendered pork fat manufacture. The esophagus contains a muscle called weasand meat which is used for the manufacture of sausage. Hog lungs are considered inedible. Hearts are sold as such or are used in prepared meats. The gullet meat is the fleshy portion of the diaphragm muscle. Commercial hog pluck consists of the heart and liver.

Beef plucks, consisting of heart, lungs, and trachea, are separated, the hearts going into the retail trade either as fancy meats or prepared meat products. The trachea proper is not used for food, except possibly as a source of tallow. Lungs may be used for edible purposes and are also converted to tankage.

The sheep pluck consists of lungs, liver, and heart. It is sold frequently with all parts included. If separated, the hearts may be converted to prepared meats. The livers are chilled and sold as such. The lungs usually go to tankage.

The pluck of the calf is especially valuable because it contains the liver. Sweet-breads are also included in this pluck and are considered a special delicacy. Some-

times the calf pluck is sold complete, including the liver, lungs, and heart. If it is divided, the liver is sold fresh and the lungs are converted to tankage. The heart is chilled, and is used either for sausage or as a fancy meat. The sweetbreads are marketed either fresh or frozen.

4. Tails

Pigtails are cut from the carcass on the cutting floor and are shipped without further processing.

Beeftails or oxtails are handled carefully to avoid bruising and discoloration and are marketed fresh or frozen or are used in canning.

5. Tripe

Tripe is prepared from the stomachs of cattle. The stomachs are rinsed in water and freed from their contents, then placed in a revolving washer to which has been added some sal soda for removing the mucous membrane. The stomach is cooked for about three hours and sold as is, or it may be cured.

6. Kidneys

Hog kidneys are removed from the carcass on the killing floor, and are promptly chilled and sold without further processing. The kidneys of cattle, sheep, and calves may be similarly handled, although they are usually sold in the carcass.

IV. CASINGS

The use of casings in the making of sausage and other table-ready meats is an old practice. As the consumption of sausage increased in the United States, sausage manufacturers, who had no dressing operations but who bought their trimmings from packers, came into existence in different States throughout the country. This, plus the fact that the processing of some animals, for instance, hogs, was somewhat of a seasonal operation, developed the necessity for cleaning, curing, and storing a surplus of casings sufficient for both the needs of the meat-packing industry and of individual sausage factories. Even today, however, some meat-packing plants do not cure their casings but sell them "green" directly to casing dealers and processors. Many of the meat-packing establishments maintain a casing department as one of their operating units.

1. Hog Casings

After removal of the viscera from the hog carcass, the pluck, hog stomach, and bung are detached. The small intestines are removed and the middle intestines separated. Any adhering fat is removed. Usually in a separate department, the operations of the preparation of the casing start with the removal of the stomach and caul fat from the viscera. The stomach is cleaned and, if intended for a casing, is turned inside out to

permit removal of the mucous lining. This is usually accomplished in a rotating cylinder employing warm water. The stomachs are next chilled and packed in salt until thoroughly cured. Hog stomachs are used as containers for head cheese.

After removal of the stomach, the bung is next cut from the viscera. It is thoroughly cleansed and any fat is trimmed off. The bung is then distended with air and measured for width. After being graded, it is turned inside out, chilled, and salted. Hog bungs are used for dry sausage and Braunschweiger liver sausage.

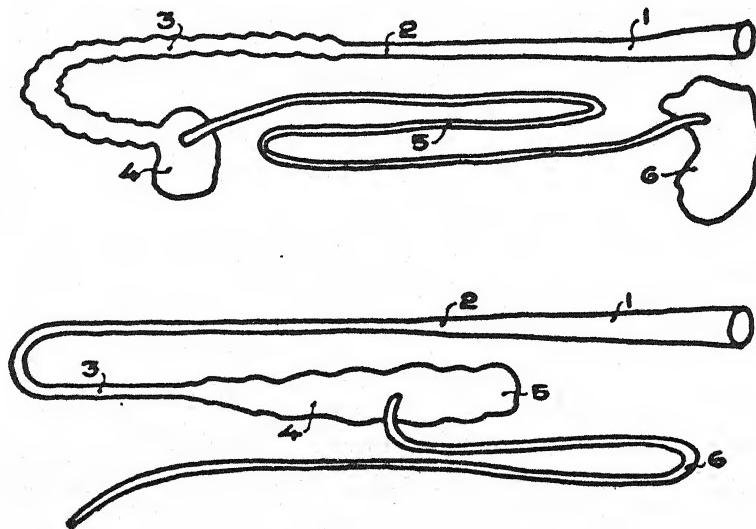


Fig. 152.—Hog and beef casings. Top: casings from hog intestines: (1) bung; (2) second end; (3) middle; (4) cap; (5) small casing; (6) stomach. Bottom: casings from beef intestines: (1) fat end; (2) wide middle; (3) narrow middle; (4) bung; (5) blind end; (6) round.⁴

After the bung has been removed from the viscera, the ruffle or mesentery is loosened. Attached to the edge of this fat are the small casings. The casing is pulled free and broken off a short distance from its juncture with the middle. It is thoroughly cleansed and chilled. The casing is next treated so that only the submucous or connective tissue of the intestines remains. The mucous coat, the muscular coat, and the serous coat were formerly removed by fermentation at 23.9° C. for 24 to 48 hours. The modern method strips the casing by mechanical methods and yields a product far better than the fermentation process.

The stripped casings are graded for diameter by inflating them with water. Any holes are eliminated by cutting the casing at the holes, thus forming shorter pieces free from holes. These casings are also graded for length and average close to 20 feet per

⁴ C. R. Moulton, "The Processing of Hog Heads, Viscera and Casings," *Meat Magazine*, March, 1936, p. 9.

piece. After grading, the casings are rubbed in fine salt and left in cure for about one week. At the end of this period, they are resalted.

Following removal of the small casing, there remains the hog middle. The fat present is removed and the casing thoroughly cleaned. It is chilled overnight in a mild brine and stripped free of the mucous layer; and the next day it is salted. A middle measures about 7.5 feet in length. Hog middles are very tender casings.

Hog bladders are turned inside out, thoroughly cleansed, and then inflated with air to assist in the trimming of all fat. They are dried inflated or salted.

Hog bungs are used for dry sausage such as Milan, Gothaer, and Arles. Middles are used for some grades of dry sausage such as frisses and small casings for fresh pork sausage, frankfurts, and chorizos. See Fig. 152.

2. Beef Casings

Beef casings include the bung, bladder, weasand (lining of the esophagus), and the intestines found enmeshed in the ruffle fat. See Fig. 152. After the carcass and parts including the intestines have passed federal inspection, the small intestines, called "rounds," are pulled away from the enfolding ruffle fat by cutting with a knife. They are thoroughly cleansed, defatted mechanically at about 32.2° C., and then turned inside out. The mucous surface and the muscular coat are removed mechanically, following which the casing is chilled. Casings at this point are inflated with air and inspected for holes, cuts, etc. They are then salted.

After removal of the rounds from the ruffle fat, there still remains the middle intestine and bung intestine. The middles are pulled apart and cleansed. The middle intestine is much heavier than the rounds and is covered with much fat. This fat is removed partly by hand and partly mechanically, following which the middles are turned inside out and the mucous and muscle layer removed.

The beef bung is the caecum or blind, and is handled essentially as the beef middle.

After the bladders have been removed and thoroughly washed, they are turned inside out, inflated, dried, and saved in the dry state. Frequently bladders are cured in salt similar to the method used with other casings. Weasands are trimmed free of any meat on the outside, washed, turned inside out, and inflated. After inflation, they are hung to dry in a room equipped with steam coils. When dry, they are punctured to release the air and then graded according to size.

Casings are made from the intestines and bladder of calves only if the animals from which they are obtained are more matured, that is, approaching the yearling size. If they are converted into casings, these intestines are handled in the same manner as beef casings.

3. Sheep Casings

Sheep casings are among the most important and valuable parts of the sheep. The demand for sheep casings is occasioned in part by their tenderness and in part by their size. The operations of preparing them are very similar to those used in hog and beef

casings. Ordinarily they are cured in salt. Sheep casings vary in diameter from approximately $11/16$ to $15/16$ inch and over.

4. Cellulose Casings

In recent years, in addition to the natural casings employed for sausage manufacture, cellulose casings have come into use. These casings are made by regeneration of cellulose in the form and size desired. Cellulose casings in general are rather tough and, unlike the natural casings, ordinarily are not eaten. When cellulose casings are used in the manufacture of frankfurts, a skin of coagulated protein forms under the cellulose during the smoking and cooking. This skin is strong enough to serve as a casing for the sausage after it is cooked. The cellulose casing, therefore, can be removed, and a "skinless" frankfurt is the result.

V. SAUSAGE AND RELATED ITEMS

Sausage usually consists of chopped meat seasoned and placed in casings, chiefly sheep, pork, and beef casings. A wide variety of meats is used in the manufacture of sausage and table-ready meats. In some cases, the entire carcass of meat animals is used. In others, certain cuts or trimmings not in great demand for other uses are employed. Consumers' demands for sausage and the related table-ready meats vary widely in different parts of the United States. This variation applies especially to the type and amount of seasoning preferred. National groups influence the kind of sausage distributed in certain markets. Many sausages have their origin in the customs of certain European countries. Thus, there are Italian, German, Dutch, French, Spanish, Polish, etc., sausages.

The processing of sausage classifies this type of product into six groups: fresh, smoked, cooked, smoked and cooked, semidry, and dry. The principal meats used in making sausage are beef and pork, to which may be added certain other ingredients, such as salt and spices. A limited amount of cereal is used in some items, the principal cereals used being corn flour, potato flour, rice flour, and wheat flour. A small amount of dry skim milk is added to some products.

The following paragraphs will present the general procedure of producing the six types of sausage, but will not discuss in detail the formulation and processing of the many varieties of each class.

1. Fresh Sausage

Fresh sausage is made from fresh meats, particularly pork. The first step in processing is the hashing of the meat by a meat hasher similar to the household meat hasher but considerably larger. Following the hashing, the other ingredients, such as salt and spices, are thoroughly mixed in mechanically. The mixture is then placed in a steel cylinder with a capacity of several hundred pounds of meat. By means of a piston actuated by air pressure, the meat is forced out of this cylinder into cone-shaped tubes called stuffing horns. A casing is slipped over the end of the horn and, as the piston forces the meat out through the stuffing horn, the casing is filled to capacity

with meat. The stuffed casing now presents the appearance of a tube, the length of which is dependent upon the particular casing which has been stuffed. At measured intervals, the casing is given a twist which divides the sausage into smaller lengths called links. The ends of the casing are knotted to prevent leakage. The linked sausage is then hung upon sticks to permit the surface to dry. Following this process, the sausage is chilled and packed for shipment, or it may be frozen prior to shipment. Fresh sausage is very perishable. An example of the composition of fresh sausage is given in the accompanying recipe.

FRESH PORK SAUSAGE, COUNTRY STYLE

<i>Meat.—</i>	85 lbs. fresh belly pork trimmings 15 lbs. fresh neck bone pork trimmings <hr/> 100 lbs.	<i>Spice.—</i>	2 lbs. salt 4 oz. fine white pepper 1/4 oz. red pepper 2 oz. sage 4 oz. granulated sugar
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The pork trimmings and spices are mixed, and ground through a $\frac{1}{16}$ -inch plate. The mixture is then stuffed into sheep or hog casings.

2. Smoked and/or Cooked Sausage

Smoked and cooked sausage covers a wide variety of products, such as frankfurts, Bologna, Polish, Berliner, and others. Practically all the meats used in smoked and cooked sausage are first cured. The type of meat, the kind of grind, the method of cure, the spicing, the kind of casing employed, the type of smoking, and other factors determine the character of the product.

Meat for sausage may be cured by three different methods: pickle curing, dry curing, and emulsion curing. If pickle curing is used, the original pieces of the meat are placed in a solution of the curing agents until cured. In general, this method is not employed in the production of sausage because the binding qualities of the meat are altered. Dry curing may be accomplished by two ways: by dry curing the original pieces; or by curing them after hashing. If the original pieces of meat are to be dry cured, they are mixed with the curing agents and stored for a number of days tightly packed in a barrel to exclude air. This method, too, is not generally used, because of the length of time required for the cure and the lack of uniformity of the cure. Dry curing of the hashed meats is the most common practice. In this method the finely chopped or hashed meat is mixed with the curing agents. An intimate mixture is quickly obtained, after which the meat is allowed to stand for a period, usually hours, for the completion of the cure and development of color. If sodium nitrite is used, the sausage may be put into casings immediately after the spices and cure have been added. The third general method of curing meats for sausage consists of mixing hashed meats with the curing agents and adding sufficient water to put the curing ingredients into solution. This mixture is allowed to stand for some hours in order to accomplish the cure. Some sausage manufacturers combine various methods of curing.

Smoked and cooked sausage may be divided into two classes, namely, that which is

made from finely cut meat, and that made from coarsely cut meat. In either type of sausage, the meats are first cured as described above.

After curing, the finely cut sausage meats are placed with the spices in a fine cutter and chopped for some minutes. This machine chops or minces the material to a very fine consistency. During this operation, water and ice are slowly added in quantities to produce a product of proper texture. The use of ice or cold water is necessary in order to prevent the meat from getting warm from the heat developed in chopping. The next operation is stuffing, which is accomplished in a manner similar to that described for fresh sausage. After the sausage has been stuffed into the casing, it is linked or tied.

Cured meats intended for coarse-cut sausage are first thoroughly mixed with whatever additional ingredients may be required and then stuffed similarly as with fine-cut sausage.

After the sausage is stuffed, the next operation is that of smoking. Smoking is an important process from the standpoint of developing the desired flavor and the permanent red color. Since smoking causes some drying, it must be carefully regulated so as not to affect adversely the appearance and palatability. Different products require different conditions of smoking. The time may vary from minutes to hours, and the temperatures, from 32.2 to 79.4° C. Generally speaking, the smoking of sausage products occurs in a shorter time than is required for products which are larger in size, such as hams and bacon.

After the product is smoked, it is immediately cooked (if it is to be cooked) in hot water. An internal temperature of approximately 65.6° C. is usually reached. This may take only a few minutes, as in the case of frankfurts, or five or six hours, as in the case of sausage stuffed into bladders.

Sometimes certain types of sausage are artificially colored, either by dipping the sausage into a solution of the dye (approved food color) and then rinsing in clean water, or by adding the dye to the cooking water.

Following cooking, smoked sausage is quickly chilled, first by spraying with cold water and then by transferring to a cooler. Storage conditions must be completely sanitary and temperatures and humidities properly controlled in order to avoid spoilage.

The accompanying recipes are for typical sausages of this category. The first is an uncooked smoked sausage, the second, smoked and cooked.

SMOKED COUNTRY SAUSAGE

75 lbs. regular pork trimmings
25 lbs. pork cheek and head meat,
or extra lean pork trimmings

Regular pork trimmings are ground through a 1-inch plate, and pork cheek and head meat through a $\frac{1}{8}$ -inch plate. After grinding, the meats are placed in a mixer, and water and the following materials added:

2 lbs. salt	$\frac{1}{8}$ oz. sodium nitrite
8 oz. sugar	$\frac{3}{4}$ oz. coriander
$\frac{1}{2}$ oz. sodium nitrate	$\frac{1}{2}$ oz. caraway

After a 3-minute mixing, the material is stuffed into medium pork casings, and linked to desired size. The product is held at 15 to 20° C. for 6 to 8 hours. After a smoking for 7 hours at 30 to 32° C., the sausage is held in the smoke house without smoke at a temperature between 65 and 71°, at 55 to 60% relative humidity, until an internal temperature of 58.3° is reached. It is removed and sprayed with warm water for 1 minute, followed by cold water for 4 minutes, then held at room temperature until dry, and thoroughly chilled before packing.

BRAUNSCHWEIGER LIVER SAUSAGE

50 lbs. hog livers
 50 lbs. skinned pork jowls
 5 lbs. peeled onions
 6 oz. white pepper
 3 oz. marjoram
 $2\frac{1}{2}$ lbs. salt
 1 oz. ground ginger
 1 oz. cardamom

The livers are placed in ice water for 30 minutes, then ground fine. The onions, spices, and salt are added, and the mixture chopped. Pork jowls are ground through a $\frac{3}{16}$ -inch plate and added to the liver mixture, followed by additional chopping. The mixture is stuffed into large hog bungs, cooked at 73.9° C. for about 2 hours (internal temperature 65.6° and up). The sausage is then chilled and smoked in a cool dense smoke at 82.2° for 12 to 16 hours.

3. Dry Sausage

There are two broad classes of dry sausage, the semidry and the dry. These sausages are almost exclusively of European origin, principally Italian, German, Scandinavian, and French. The dry salamis and dry cervelats are typical of hard dry sausage. The semidry or soft dry sausages are sometimes called summer sausage. There are many varieties of both kinds of dry sausage, and the classification given here is not an exact one.

(a) Semidry sausage

Sausages such as the varieties of soft cervelat, Thuringer, soft salami, cooked salami and mortadella fall into this classification. An example of a soft dry sausage is given in the accompanying recipe for soft cervelat.

SOFT CERVELAT

5 lbs. pork shoulder fat
 $1\frac{1}{2}$ lbs. hearts
 $7\frac{1}{2}$ lbs. beef trimmings

The beef and hearts are ground through a $\frac{1}{8}$ -inch plate and the fat through a $\frac{3}{4}$ -inch plate. The following ingredients are added:

3 lbs. 6 oz. salt
 8 oz. sugar
 3 oz. ground white pepper
 $1\frac{1}{4}$ oz. sodium nitrate
 $\frac{1}{4}$ oz. sodium nitrite

This is mixed 2 minutes and ground through a $\frac{1}{8}$ -inch plate. Three oz. of whole black pepper are spread over the meat, mixed 2 minutes, the mixture is stuffed into casings and held 1 day at 15° C. and 80% relative humidity. The sausage is smoked 60 hours at 32 to 35° C., followed by 6 hours' smoking at 49° . It is then sprayed with warm water, chilled with cold water, and further chilled in a cooler before shipping.

(b) Hard Dry Sausage

Examples of this class are smoked dry salami and cervelat, the Italian unsmoked salami, chorizos, mortadella, and pepperoni. The processing of hard dry sausages requires facilities for the slow, even removal of the moisture from the sausage. Before air conditioning was available, such products were made chiefly in the winter. Pork is an important ingredient and, since many of these products are eaten without cooking, they must be processed to kill trichina. Chuck is a common source of beef for dry sausage. The meats are cut to the proper degree of fineness or coarseness, mixed with

the curing ingredients, and stored for a period of time sufficient to complete the cure. Following stuffing into the proper casing, many dry sausages are held in a "green" hanging room. Temperatures are maintained in this room between 12.2 and 15.6° C. and the humidity between 60 and 70%. In the green hanging room, the initial color develops and the moisture is removed from the surface. The sausage is usually left in the green hanging room 24 to 36 hours, and then removed to the drying room. Temperatures in this room are maintained at 8.9 to 12.2° C. and the humidity 65 to 70%, the product being hung to permit free circulation of the air. The drying period varies with the type of sausage but usually takes 20 to 60 days. The accompanying recipe is for a typical hard, dry, unsmoked sausage.

ITALIAN-STYLE SALAMI⁵

30 lbs. fresh beef chuck
50 lbs. fresh lean pork (extra lean)
20 lbs. regular pork trimmings
3 lbs., 6 oz. salt
3 oz. sodium nitrate
8 oz. sugar
4 oz. ground white pepper
4 oz. whole white pepper
1 oz. peeled garlic

The beef chuck is ground with the garlic. The pork trimmings are ground separately and mixed with the beef curing and seasoning ingredients. The mixture is stored at 3.3° C. Hog bungs are used for Italian salami. Casings must be free of fat in order to permit drying later. The meats are stuffed into the casings which are then washed. The sausage is hung in the green hanging room for 24 to 36 hours. After this preliminary drying, it is bound with hemp and placed in the drying room. About 60 days are required to accomplish the drying.

4. Products Related to Sausage

There has been an increasing consumer demand for certain types of meat products, including meat loaves, chili con carne, tamales, scrapple, etc. Many of these items are highly localized specialties. Essentially the same meat materials are used in sausage as in loaves; and the handling of both types of product up to the time they are cooked or baked is very much the same. Loaf products, however, are not smoked. Some loaves are stuffed into artificial casings.

5. B. A. I. Special Regulations Pertaining to Sausage

In addition to the general regulations on meats, the following is a résumé of some of the special B. A. I. rulings which apply to sausage:

The only animal casings which may be used for containers are those from cattle, sheep, swine or goats.

Certain dyes approved by the B. A. I. may be used for coloring casings under conditions which do not color the meat.

When declared, sausage may contain up to 3.5% individually or collectively of cereal, vegetable starch, starchy vegetable flour, dry milk, or dry skim milk.

Milk may be added to sausage provided the moisture of the product is not in excess of the amount prescribed by the B. A. I.

Soybean flour cannot be used in sausage but can be used in meat loaves.

⁵ *Sausage and Meat Specialties, Part 3.* The Packer's Encyclopedia, The National Provisioner, Chicago, 1938, p. 198.

For the purpose of facilitating grinding, chopping, and mixing, not more than 3% of water or ice may be added to sausage which is not cooked. Sausage which is cooked may contain not more than 10% added water.

Special regulations apply to products containing pork which are normally eaten without cooking. Such products must either be heated to 58.3° C. in all portions of the meat or article, or the pork may be held at low temperatures according to Table 57:

TABLE 57
HOLDING TEMPERATURES FOR PORK

Temperature, ° C.	Group (1), days	Group (2), days
-15.....	20.....	30.....
-23.8.....	10.....	20.....
-28.9.....	6.....	12.....

Group (1) comprises the meat or product in separate pieces not exceeding 6 inches in thickness. Group (2) comprises the meat or product in pieces or layers or within containers, the thickness of which exceeds 6 but not 27 inches. A third method involves dehydration of the product in the presence of the curing agents under specific conditions set up by the B. A. I. Preparation of hard dry sausage is an example of this third method. Any one of the three methods destroy trichina (*Trichinella spiralis*).

VI. CANNED MEATS

1. General

Canned meats or meats in glass jars form an important item on the list of products marketed by a meat-packing plant. It would be impossible to list all the canned meat items produced because of their number, but one may get some idea of the variety of items canned from the following more important items: roast beef; corned beef; corned beef hash; dried beef; whole, half, and quarter hams; chopped spiced ham and chopped spiced luncheon meats; sliced bacon; sausage; vinegar pickle products such as pigs' feet; and preparations containing meat such as stew, chili con carne, soup, etc.

The sterilization of a food product in a tin, glass, or other similar container is a most effective method of food preservation. Food in suitable containers and properly sterilized can be kept in a wholesome and appetizing condition for an indefinite length of time. The preservation of canned foods is accomplished by sealing the product in the container and destroying by heat any bacteria capable of producing spoilage. Since the container is sealed, once the bacteria are destroyed no new ones can gain access.

The aim in a canning procedure is to accomplish commercial sterilization, that is, destruction of all bacteria harmful to man and which may cause spoilage. The most persistent type of bacteria in meat are the spore formers; vegetative forms of bacteria are not heat-resistant, and usually are easily killed in a canning procedure. Common vegetative forms of bacteria and the vegetative disease forming bacteria are usually of no importance as food spoilage bacteria because they are easily killed. The length of

time required to kill bacteria by heat varies with the temperature employed, the kind of bacteria, the presence or absence of spore forms, the moisture content of the medium, the presence or absence of certain substances such as acids and salts, the protective action of oil or fat, and other factors. Moist heat is most effective, but may be offset by the presence of oil or fat, which prevents the moist heat from reaching the bacteria. Acids greatly reduce the resistance of spores to heat. Salt is highly effective in assisting heat to kill bacteria. Sodium nitrate also is effective against certain organisms, for example, *Clostridium botulinum*. It is good practice in handling the meats prior to canning to employ proper sanitation, so that the inoculation of the raw materials is relatively light and there is little chance of leaving a disproportionately large residuum of bacteria after the canning procedure.

The time and temperature required to process a canned product properly also depend upon the size and shape of the container and the type of product. Canning schedules must be set up by actual test on each product in the type and size of containers to be employed. The type of cooker employed also enters into the time required. It is the purpose of a canning schedule to guarantee that all parts of the product in the can reach the temperature necessary for sterilization and are maintained at that temperature for a sufficient period of time.

2. Containers

Normally, there are two types of containers used for canning meat, tin cans and glass jars. Most meat products are put up in tin cans, which may be enamel lined. The purpose of the enamel lining is to preserve the normal color of the product as well as to avoid discoloration of the can itself. The use of enamel is limited to the type of can requiring no soldering, since the heat required for soldering would damage the enamel.

There are two general styles of cans employed for meat canning: the hole-and-cap or soldered can; and the open-top or sanitary cans. The hole-and-cap can has a top with a hole in the center by means of which the can is filled. Sanitary cans have one end which is entirely open and which is closed after filling by a double seaming of a top onto the can without the use of solder. Sanitary cans are the type usually used.

Glass jars are used for products of high acidity or those packed in heavy brine. The metal closure for the glass jar must be protected from the contents by a suitable liner or by being lacquered.

3. Canning Procedures

(a) Preliminary Treatment of Meats

Sometimes meat which is to be canned is cooked or processed before being placed in the container. The preliminary cooking is necessary to preshrink the meat in order to avoid subsequent shrinking in the can, and to give a well-filled appearance to the contents of the can. Luncheon meat, spiced ham, chopped pork shoulder items,

chili con carne, sausage, and brains are the chief canned items which receive no preliminary processing before canning.

After the preliminary cooking, the meats are trimmed free of fat, gristle, bones, etc. If necessary, the meat may be cut into smaller pieces prior to canning.

(b) *Filling the Container*

There are three general methods of filling the container: by hand, by a filling machine, or by a stuffing machine.

Such items as tongue, brains, tripe, sliced bacon, Vienna sausage, etc., are placed in the can by *hand filling*. Care is taken to control the weight or number of pieces.

Certain products flow, especially if they are properly heated. The *filling machine* is a device which causes the meat to flow in a continuous stream from outlets of a proper size for the particular can employed. The cans are held under these outlets and receive a measured amount of the product. Certain of these filling machines operate at high rates of speed, filling several hundred cans per minute.

Solid or bulky products such as corned beef are placed in cans by means of *stuffing machines*. The proper quantity of meat is weighed out and placed in a chamber provided with a plunger. The plunger forces the meat compactly into the can.

(c) *Closing the Container*

The method used to close the container varies with the style of the container. With the hole-and-cap cans, the cap containing a small vent hole is applied to the opening. The can is then placed in a capping machine where it is soldered either automatically or by hand. The open-top or sanitary can is closed and sealed by double seaming of the top in an automatic machine.

Normally, canned meat products are sealed under vacuum. There are several advantages to be gained by the use of the vacuum:

(a) Removal of the oxygen from the air minimizes discoloration of the meat and inhibits rancidity development in the fat.

(b) Inside corrosion of the can, if due to oxygen, is prevented.

(c) Since vacuum-sealed cans have a characteristic appearance, namely, that their ends are snapped in after the product is cool, it is possible to detect leakers by the absence of this normal appearance. However, not all cans which do not have their ends snapped in are leakers. Overfilled cans or cans which did not receive a complete evacuation may have the appearance of leakers.

(d) Cans not sealed under vacuum sometimes distend their ends under certain conditions of temperature and altitude. This is minimized with vacuum-sealed cans. The vacuum sealing of glass containers is particularly advantageous because the atmospheric pressure on the lid helps to maintain a tight seal.

Two methods are used to obtain a vacuum: The container and its contents are placed in a mechanical vacuum and closed while under vacuum; or the air in the container is expanded by heat and replaced largely by steam, after which the can is

sealed hot. The second method is little used at present. The vacuum obtained in any particular can will vary with the size of the container, amount of fill, temperature of the contents, amount of air trapped in the products, and other factors.

Different methods are used to close a can under vacuum. The can with a vent hole may be placed in a vacuum chamber obtained mechanically and soldered shut while in that chamber. Perhaps the best method is that used for only the open-top type of can—the lid is loosely crimped on and the can placed in a vacuum chamber where the final operations of double seaming are completed.

(d) Processing

The sterilization process follows as rapidly as possible the hermetic sealing of the can. The time and temperature for the particular size of container for a certain product have been established as indicated previously in this section. This time involves not only the time required for sterilization of the product but also that necessary to cook the products properly. Overcooking may cause the product to lose its characteristic form or to shrink excessively. The shrinkage results in the formation of considerable liquid which has been cooked out of the meat. If this shrink is excessive, the consumer may object. Usually a large portion occurs in the precooking of the meat; in addition, however, care must be exercised in the time and temperatures used in the processing in the can.

There are two general methods of raising the temperature of the contents of the cans to the desired degree. The cans may be packed into a retort which is sealed up, and into which is admitted steam under pressure. After the proper interval of time, at a given steam pressure, as called for by the previously determined schedule, the steam is turned off, the cans are cooled by running cold water on them, the retort is opened, and the product is removed. Sometimes the cans are sprayed with water to cool them after removal from the retort. For products of large volume, there are continuously operating retorts.

The second method of heating the product is immersion of the cans in a liquid bath for a period sufficient to obtain the desired temperature. Frequently the cans are carried through such a bath on a conveyor whose speed is adjusted to allow the time necessary for processing.

After the cans have cooled, they are washed, labeled, or wrapped, as the case may be. Cans intended for export and those used by the armed forces are usually lacquered on the outside to prevent rusting by salt water. Labeling may be done by hand or mechanically.

VII. CURED MEATS

1. General

Meat curing is the process whereby certain materials known as curing agents are introduced into the meat, frequently over a period of time, with the result that the meat product is altered in a characteristic fashion in regard to its keeping quality,

flavor, and color. The curing process assumes a great variety of patterns as it is carried out in the curing of particular meat products. In some of the products one kind of result of meat curing may be more important than another. For example, the preservative action of the salt in some bacon and certain hams for export is far more important than considerations of flavor or color. In domestic bacon, for which the time between production and consumption is relatively short, the consideration of flavor and appearance outweighs the effects of the curing process on the extension of the life of the product. Such considerations as these, plus the great variety of products cured, plus variations in methods of cure occasioned by the preferences of localities or national groups, make it difficult to describe completely the processes by which all cured meats are produced.

Meat curing as a process frequently has associated with it other operations, so that, in the preparation of a particular product, the curing of it is but one step among several. For example, many meats like ham or bacon are smoked in addition to being cured. Other cured meats are processed into sausage. Some are canned.

From both the consumers' and the producers' points of view, cured meats have as probably their most important property a characteristic flavor. The production of this flavor characteristic of this product offers the producer his greatest chance of individuality in the entire list of meat products he may prepare. Sausage, frequently a cured meat item, is the only other product which offers such an advantage. Therefore, each producer of cured meats usually has his own special process and formula. The consumer, on the other hand, frequently finds his desires in flavor best satisfied by a particular brand or style of cured meat.

Curing is usually carried out in an insulated and refrigerated room. The rate of curing increases with temperature rise; but, since many curing procedures require a number of days for completion, there is danger of spoilage if the temperature is too high. Most curing operations are carried out at temperatures in the neighborhood of 2.2 to 3.3° C. Curing is accomplished in a variety of containers, such as tierces, round vats, rectangular wooden vats, concrete vats, and wooden or metal boxes. The particular container to be used depends upon the product being cured and the method of cure. After each use, these containers are carefully washed and steamed.

2. Curing Methods

As has been indicated, there are a great variety of ways of curing meats. It is possible, however, to distinguish four basic methods among the countless processes practically employed. Fundamentally the curing process consists in the obtaining of a uniform distribution of the curing agents. Until this is obtained the results of the curing process do not occur, and in most curing processes the time required for uniform distribution of the curing agents sets the length of the cure.

The curing agents permitted by the Bureau of Animal Industry of the United States Department of Agriculture are sodium chloride, sugar, sodium nitrate, sodium nitrite, and vinegar. Of these, the first four are the most important. The function of each

has been discussed in Volume I, page 453 *et seq.* on meats. The four basic methods by which uniform distribution of these curing agents may be obtained are as follows:

(a) *Dry Cure*

The dry cure method is one in which the product may be rubbed with the dry mixture of curing agents and allowed to stand until, by the process of diffusion, the curing agents penetrate the interior of the meat and become fairly uniformly distributed. This process is necessarily a slow one, but for certain types of cures is the most suitable. Belly bacon, the kind generally consumed in the United States, is usually prepared by this method.

(b) *Pickle Cure*

In this method, the curing agents are dissolved in water to form a pickle, in which the meats may be soaked until, by a process of diffusion and water interchange, the curing agents penetrate the interior of the product, become fairly uniformly distributed, and reach a concentration which is governed by the concentration of the curing agents in the pickle.

(c) *Injection Cure*

A recent modification of the pickle cure has been developed for certain cured cuts, notably pork hams. Advantage is taken of the fact that the skeletal muscle structure of the living animal is fed by the flow of blood through the vascular system. These arteries and veins remain in the muscle and provide an excellent method for distributing a material such as a curing pickle. By inserting a needle into the proper artery and pumping through this needle the requisite amount of pickle, the time required for complete distribution of the curing agents is cut down enormously. This method is known erroneously as the vein pumping method. More properly it should be called the vascular pumping method, since the pickle is distributed by both arteries and veins.

(d) *Comminuted Meats*

Those cured meats which are rather finely ground, for example, sausage, require only that the curing agent be mixed with them in order to obtain proper distribution of the latter. One might say that such cures can be made instantaneously. However, because the time required for distribution is so small, there is insufficient time for certain of the curing agents, notably the nitrate and the nitrite, to react. Consequently, cured comminuted meats are either permitted to stand or "cure" for some time, or the reactions are speeded up by heat. Thus it is possible in the canning of certain meats to employ a "hot cure," the curing reaction taking place during the warming up of the product prior to sterilization.

3. Preparation of Cure Mixtures

Pickle is usually made in large tanks of wood containing pipes for heating it by steam and another set of pipes for cooling. Compressed air is usually used for agitation. The ingredients, sugar, sodium nitrate, and sodium nitrite, are carefully weighed in. In the case of salt, the required amount is added in the form of a previously prepared, saturated solution. The concentration of salt is regulated by measuring the density of the pickle, usually with a float salometer (see page 372), and adding water or saturated brine as required. The pickle is cooled to the temperature of the curing cellar before it is used. After meats are cured, there is some residual pickle which contains valuable ingredients, although usually not in the concentration originally present. Such pickle is frequently reclaimed. The first step in the reclaiming usually is heating it to boiling, for two reasons: first, to sterilize; and second, to coagulate any of the albuminous materials extracted from the meat. *Second pickle*, as this solution is termed, is filtered, and then brought up to the desired strength by the addition of the proper amount of each curing agent.

Dry cure mixtures are prepared by weighing the proper amounts for a given batch and then obtaining a uniform mixture by use of a mechanical mixer such as a barrel churn.

4. Specific Cuts

The following section will take up in some detail the curing of specific cuts. The principal meats cured are pork and beef. For convenience, the description of the methods of cure will be grouped according to the type of meat and not according to the method of cure employed.

(a) Pork

Pork Hams.—Hams are usually cured by a combination of pumping and soaking. Hams are usually vein pumped; and a small amount of pickle is also introduced with another needle directly into the muscle without regard to the vascular system. The hams are then placed in a tierce or vat and covered with pickle. It is customary to use one formula for the pumping pickle and another for the cover pickle. Since too much water pumped into the ham is objectionable, the pumping pickle is made quite concentrated. The pickle may contain either sodium nitrite or sodium nitrate, but the present practice is to combine the use of both. Such a cure is termed a mixed cure. Typical formulas for mixed cures for pork hams may be as follows:

Ingredient	Pumping pickle, %	Cover pickle, %
Sodium nitrate	0.10	0.08
Sodium nitrite	0.10	0.05
Sugar	2.5	1.5
Salt	24.0	15.0

The pumping needle, connected to a reservoir of the pumping pickle, is inserted in the main artery (iliac) of the leg, which, by careful trimming, has been exposed, and an amount of pickle is pumped in proportionate to the weight of the ham. This will vary somewhat with the formula of pickle employed, but is usually in the neighborhood of 8% of the weight of the ham. In addition, the needle may be inserted directly into the meat in the shank and in the butt end and a couple of ounces of pickle injected at these points.

The next step is placing the ham in a vat or tierce for the completion of the cure. The proper packing of the hams in the container is important in order to secure proper circulation of the pickle and to prevent the hams from being squeezed out of shape. Curing vats may hold as much as 1400 pounds of ham each.

After the hams have been packed in a container, they are covered with the cover pickle, approximately 5 gallons of pickle being used per 100 pounds of meat. If a vat is used, a cover of slats is laid over the meat in order to keep it submerged.

The time of cure varies with the particular practice of the packer. Three to 15 days probably cover the extremes of the times employed.

On completion of the cure, the pickle is drained from the container and the meat "pulled." The excess pickle is permitted to drain; and the hams are washed, branded, and sent to the smokehouse if they are to be smoked.

Curing of picnics and shoulders is practically the same as that for hams with due allowances for differences in size. Sometimes, these hams are not vein pumped, but receive injections of pickle directly into the muscles in certain areas.

It was a frequent occurrence in the days prior to vein pumping, when long cures were required for hams (60 to 90 days), to have the bone and certain areas immediately in the vicinity of the bone become sour. The spoilage was of bacterial origin and probably occurred before the salt of the pickle reached this region. While ordinarily it did not invade the meat tissue of the ham, it was highly objectionable and caused the packer considerable loss, since salvage of the ham, if at all possible, could be accomplished only by boning out the ham. With the advent of the vein pumping system of cure, the period of cure has been greatly shortened; this fact, together with prompt handling and sanitation in other operations prior to curing, has virtually eliminated bone sours in hams.

Bellies for Bacon.—The dry salt mixture for curing bellies is made of rather finely divided salt and sugar in order to obtain a good distribution of the curing agents over the bellies. There is considerable variation in the formula for this curing mixture among the various packers. Today some still prefer a straight nitrate cure, while others have a straight nitrite cure or a mixed cure. The following is a typical mixed cure for 100 pounds of bellies: 3 lbs. salt; 2 lbs. cane sugar; $\frac{1}{4}$ oz. sodium nitrite; and 2 oz. sodium nitrate.

Most bacon is cured in boxes, which may be of metal or wood, although metal is preferred. The boxes are usually lined with a wax paper. The bellies are packed carefully into the box layer by layer, with the flesh side up. As each layer is placed in the box, a weighed amount of the curing mixture is sprinkled over it and carefully

distributed. When the final layer has been placed in the box, it is covered over with wax paper and the lid of the box forced down under considerable pressure. Every effort is made to exclude air from the box and avoid air pockets, since the presence of air will cause discoloration of the bacon. Boxes used for curing bacon may contain as much as 900 pounds of bacon.

The period of cure is approximately 25 to 30 days at 3.3° C. At this time, the box is opened and the bellies removed, washed, and sent to the smokehouse. The salt usually extracts moisture from the bacon, so that there is normally present a small amount of pickle formed in this way.

Some variations of this procedure are practiced in order to avoid the rather large outlay for boxes required. Bellies may be cured in vats if the vats are frequently overhauled, or they may be partially cured in vats and finished in a cover pickle. Pickle curing of bellies is sometimes practiced. Pickle-cured bellies tend to make watery bacon; and, therefore, the best grades of bacon are dry cured.

Other Cured Pork Cuts.—Hams are dry cured for special trade requirements. Italian hams have the aitch bone removed before they are cured, which enables them to be pressed to a thickness of about four inches after cure. They may be rubbed with salt, nitrate, and a pepper mixture and cured for about 30 days. Since the Italian hams are frequently eaten raw, they are sufficiently dried after curing to destroy any trichina which may be present.

Butts are also dry cured for special trade. Jowls are soaked in saturated salt brine overnight and then dry cured for 15 days.

Many meats for export trade require special handling. This is particularly true for meats exported to England. Ordinarily, the export trade in meats with England is not appreciable; but, since the onset of the second World War, there has been the need for preparation of considerable pork for export to England. English bacon is mainly of the Wiltshire variety, and usually consists of the whole side of a hog, including the ham and shoulder. The Wiltshire cure is usually a pickle cure in a saturated brine.

Boneless pork loins or Canadian bacon are usually pickle cured, the cure taking 20 to 30 days. Following the cure, they may be stuffed into a cellulose casing and smoked. Since Canadian bacon may be eaten without cooking, pork loins intended for the manufacture of this product are held frozen under conditions sufficient to destroy trichina.

(b) Beef

Normally, beef of high quality is marketed as fresh beef. Such beef is obtained from animals of the correct age which have been properly fed and finished prior to marketing. There are, however, a number of beef animals marketed whose quality is not sufficiently high to permit some or all of the beef obtained from their carcasses to be cut up into the ordinary market cuts. This beef is usually canned or used in sausage making. Certain cuts can be made more attractive and palatable by curing and smoking. The following are the more common cuts of beef which are cured:

Corned Beef.—Corned beef may be prepared from any part of the carcass, but the plate (brisket) or rump pieces are usually selected. Corned beef is prepared by rubbing salt on each piece, packing the pieces in a layer, and placing over the entire lot about a 20% salt brine containing sugar, nitrate, and nitrite. It takes about 25 days at 3.3° C. to complete the cure. During this period, the meat is overhauled two or three times. Briskets are sometimes vein pumped.

Corned beef may be sold after cure without further processing, or it may be canned.

Beef Hams.—Beef hams are cured for the manufacture of dried beef. In this product color is of extreme importance. Beef hams may be cured in a pickle composed of salt, cane sugar, and nitrate. Formulas for this pickle vary considerably with each packer. A typical formula may be: salt, 14%; cane sugar, 6%; and sodium nitrate, 0.25%. The hams are packed in tierces or vats much in the way pork hams are packed. The cure is quite long and takes about 100 days. Recently, vein pumping has been applied to beef hams with considerable success and the cure shortened to 20 days.

Beef Tongues.—Beef tongues may be pickle cured or vein pumped. If pickle cured, the cure takes about 55 days; vein pumping reduces this time to 5 days.

VIII. SMOKED MEATS

When meats are pulled from cure, they are ready either for smoking or cooking. This section will deal with the production of smoked meats.

1. General

Smokehouses are usually several stories in height. At the bottom is the fire pit, 6 to 8 feet below the smoking level. This pit has a door in it to permit admission of air for the necessary ventilation. Above the pit are the various smoke floors, usually consisting of steel gratings which permit the smoke to rise through them. The walls of the smokehouse are surfaced smooth; a false ceiling is built 2 or 3 feet below the roof, and is sloped to several openings for escape of the smoke. Usually, steam coils are installed in the house in order to obtain heat in addition to that produced by the fire. Smokehouses also frequently have a means of admitting steam in order that the humidity may be controlled. Since there is some danger of fire, it is customary to equip the house with sprinklers. In addition, there is a large steam line leading directly into the lower part of the house. Should a fire develop, opening this steam line will flood the smokehouse with steam and smother the fire.

The older method of firing the smokehouse consisted of heating it with a fire of hardwood and then smudging the embers with sawdust. Because of the expense of hardwood, modern practice now uses steam heat for heating, but retains the sawdust smudge for generation of the smoke. There are various methods of obtaining the sawdust smudge, such as the use of oil or gas flames directed against a pile of sawdust, charcoal briquets, etc. Hickory sawdust is preferred for the smoking of meats; however, any hardwood sawdust such as oak, maple, beech, birch, walnut, or mahogany may be used.

In the modern smokehouse, strict care is given to the control of temperature and humidity. Smoking schedules call for very specific temperatures for prolonged periods. Regulation of the humidity is important in order to control the rate of drying and to prevent "shelling" of the product.

It is impossible to give more than general figures on the temperatures and times for smoking. Each product usually has its own schedule, and, normally, each packer has his own opinion as to what is the proper schedule. Bacon usually receives a smoke in the neighborhood of 18 to 24 hours; temperatures may be as high as 54.4° C. On the other hand, in processing the so-called tender cooked ham, the smokehouse temperatures may be as high as 71° and the period of smoke in the neighborhood of 16 hours. For products as dry as dried beef, the smoking period may be 3 or 4 days. In general, one may say that smokehouse temperatures range between 43 and 71° C. and that smoking periods vary from as short as a few hours in the case of such items as sausage to as long as several days in the case of beef hams.

2. Preparation of Meats for Smoking

In preparation for smoking, the meats are washed and scraped dry on the skin side. If the meats are to be branded, this operation is next performed. Branding may be carried out either by burning a design with a hot iron or by inking. After the meats have been branded, they are hung on smokehouse trees or trolleys on which they are transported to the smokehouse. Pork and beef hams, picnics, and shoulders are suspended on the trees by means of a loop of twine threaded through the shank. Bacon bellies are suspended by forcing a toothcomb hanger into the flank end of the belly, which in turn is hung upon the tree. Smaller cuts such as butts and squares may be laid on trays or suspended in a cotton stockinet. Stockinets are also used in supporting pork hams in order to shape the ham properly. Other devices exist, as the use of muslin bands passed around the butt of the ham.

3. Results of Smoking

Wood smoke contains small amounts of formaldehyde, acetaldehyde, acetone, phenol, acetic acid, methyl and ethyl alcohols, and many other compounds. Smoking of meats has a preservative action which, undoubtedly, is due to the presence of some of the compounds listed above. Smoking greatly alters the appearance of the meat and adds a rich brown color to it. These more or less chemical effects are accompanied by the drying action of the heat and the effects of the temperature on any microbial life and on the meat pigments. There is a very definite improvement in the internal color of cured meats during the smoking process.

4. Handling after Smoking

After the smoking operation, it is good practice to chill the meats as rapidly as possible. This is especially true of vein pumped products which at all times require adequate refrigeration. Smoked meats are frequently wrapped for retail trade to protect

them in handling, or, in the case of such items as bacon or dry beef, they may be sliced and packaged for sale.

IX. THE MANUFACTURE OF GELATIN

Tissues containing the protein, collagen, may be used in making gelatin.⁶ Since gelatin is primarily a food product, only those materials of an edible nature are used in its manufacture. The processing of these materials into gelatin is carried out under the strictest sanitary conditions, and it is to the credit of the gelatin industry that gelatin is one of our food materials with the lowest bacterial count.

Collagen is found in a number of animal tissues, such as bone, tendons (sinews), hides or skins, and connective tissue. Of these, bones and skins are the source materials for food gelatin. The process of gelatin manufacture varies somewhat with the type of materials employed. If fresh bones are used, mere boiling with water is sufficient to convert the collagen to gelatin. This boiling, however, may be preceded by an operation to remove the grease. Extraction of the gelatin from bone is greatly improved by first acidulating the bone with dilute (several per cent) hydrochloric acid. This dissolves from the bone calcium phosphate, which can be precipitated by the addition of lime to yield the acid phosphate (CaHPO_4), which in turn is removed by filtration. The collagen extracted by this process, after washing and neutralization of the residual acid with lime water, may be made directly into gelatin. The dried product is known as ossein. Extraction of the ossein with hot water (70–90° C.) converts the collagen into gelatin through hydrolysis.

If the materials are hides or skins, two methods of getting the collagen in a condition for easy conversion to gelatin and extraction of the gelatin are possible. The stock may be "cured" or limed by placing lime on it and holding it in pits for a number of days. This swells or plumps the stock and removes much of the mucin. The lime pits are square, wooden, or cement tanks about 4 feet deep, usually sunk in the ground. The soaked or washed stock is thrown into a suspension of milk of lime contained in the pit and at intervals during the time of cure is stirred or agitated. The time of cure varies with the size and kind of raw material, and for thick hide pieces may be up to 6 weeks. A second method of curing, which offers the advantage of reducing the time for conditioning the stock, involves acidulation of the skins by means of a 0.2% solution of hydrochloric acid. In this process, the washed stock is placed in a round tank of large diameter in which is provided means for vigorous agitation. The time required for plumping of skins by this method is reduced to a matter of hours, usually in the neighborhood of about 16 hours. At the end of the cure, the acid is removed by washing.

The remainder of the processing employed in the manufacture of gelatin is essentially the same regardless of the type of stock. The extraction process converts the collagen into gelatin by hydrolysis. The higher the extraction temperature and the longer the

⁶ For a discussion of gelatin see Jerome Alexander, *Glue and Gelatin*. Chemical Catalog Co., New York, 1923.

stock and liquor are exposed to it, the further the hydrolysis proceeds, with the result that products other than gelatin may be obtained if conditions are too severe. The extraction, therefore, is made as quickly as possible and at the lowest temperature possible. In practice, a series of extractions are made, each succeeding one at a slightly increased temperature. Each extraction is known as a run.

Two types of kettles or cookers are used: open tanks, or pressure tanks. Ordinarily, the open tank is used only with hides or ossein stock. The pressure tank is used for bones. The first extractions produce the best gelatin as far as ability to form a strong gel in a minimum of time and as far as viscosity are concerned. In operating a number of tanks simultaneously, it is customary, therefore, to combine the gelatin of the same run from the various tanks. The temperature employed in open-kettle boiling may start as low as 54° C. on the first run and finish as high as 90° on the last run. Six or 7 extractions may be made on the same stock. Pressures up to 45 pounds of steam may be employed in pressure tanks. A run in an open kettle usually takes from 2 to 6 hours, depending on the nature of the stock and the temperature employed. Pressure-cooked gelatin is usually of inferior grade.

Since the extraction of the gelatin is accomplished more easily by pure water than by a solution of gelatin, the gelatin liquors obtained in the various runs are rather dilute, containing 2 or 3% gelatin. The next step in the process is the removal, usually by filtration or some similar process, of any material suspended in the liquors, and then their concentration by evaporation of the water, usually in a vacuum evaporator. The degree of evaporation required is governed by the jelly strength of the gelatin and the initial concentration of the liquor. The purpose of increasing the concentration of the gelatin is to obtain a solution which, upon chilling, will form a fairly stiff gel that will support itself on a net. The remainder of the moisture is then removed by air drying.

The concentrated glue liquor is chilled into a continuous sheet, which is then cut and spread upon nets. There are many devices for this purpose. One such device receives the concentrated liquor upon an endless belt, which passes through a refrigerating tunnel. While in this tunnel, the gelatin sets into a gel, and the continuous sheet of chilled jelly, upon emerging from the tunnel, is automatically cut into sheets of the required size, which in turn are automatically spread upon drying nets. These nets are then transferred to a wind tunnel; and further drying is accomplished by blowing filtered air across the jelly. At first, the air temperature is kept low in order to avoid melting of the jelly; but as the concentration of the gelatin increases, the temperatures are raised, thus reducing the time required for the drying.

The sheets of gelatin which have been dried down to about 10% moisture are stripped off the drying nets and ground to the desired fineness.

Throughout the entire operation, strict sanitation is practiced. All equipment is designed to permit easy cleanup; all piping is of the sanitary type. Frequent and regular periods of cleanup are practiced in which sterilizing agents such as hypochlorite are freely used. A constant check is maintained on the bacterial condition of the product at various stages in the processing. Gelatin solutions are such excellent me-

dia for bacterial growth that such measures are imperative. The high-quality gelatin manufactured today has a very low bacterial count, and it should be noted that this is accomplished without the use of any preservatives.

X. SANITATION MEASURES

1. Meat Inspection

While most of the states have laws governing the production of meat, the system of inspection set up by the Federal Government is the one usually thought of when the term meat inspection is mentioned. The Bureau of Animal Industry of the United States Department of Agriculture came into existence in 1884 as the result of an Act of Congress. The first duties of the B. A. I. were concerned "with the building up and protecting of the livestock industry of the United States." This broad field of activity has occasioned the formation within the Bureau of divisions charged with specific duties. These are:

- Division of Business Administration
- Animal Disease Station
- Animal Husbandry Division
- Animal Nutrition Division
- Field Inspection Division
- Interstate Inspection Division
- Meat Inspection Division
- Pathological Division
- Division of Tick Eradication and Special Diseases
- Tuberculosis Eradication Division
- Virus Serum Division
- Zoological Division

As the titles indicate, many of the divisions are concerned with live animals, either working to control or eradicate animal diseases or to improve through breeding the quality of animals. The division charged with the inspection of slaughtering establishments is the one concerned with here, since its work relates directly to meat production.

The Meat Inspection Division (which was transferred from the Bureau of Animal Industry to the Food Distribution Administration in 1942, see page 110) provides a service consisting of seven essential parts, namely, sanitation, ante-mortem inspection, post-mortem inspection, product inspection, laboratory inspection, control and destruction of condemned material, and marking and labeling. A description of these procedures follows, as given by John R. Mohler, Chief of the Bureau.⁷

"Meat inspection is not inaugurated at an establishment until it and its premises have been made to conform to the requirements as to sanitation and facilities for the conduct of inspection. Thereafter the maintenance of sanitation in accordance with advanced principles of meat hygiene is required. Examples of essential requirements in sanitation include: potable and ample water sup-

⁷ John R. Mohler, *The Bureau of Animal Industry and Its Work*. Washington, D. C., April, 1941.

plies; sanitary drainage system; abundance of natural and artificial light; sufficient ventilation; and adequate hot water supply for clean-up purposes.

"The purpose of ante-mortem inspection is to search out, mark, and segregate from the lot of animals for condemnation or, when conditions warrant, for separate slaughtering and post-mortem inspection, any and all that show indications of disease or unfit condition. Those found unfit for food purposes are condemned and destroyed, while those less affected, after segregation, are marked by affixing to the ear a serially numbered metal tag bearing the imprinted phrase 'U. S. Suspect' and are held under control for separate slaughter. Animals found apparently fit are passed for slaughter.

"Post-mortem inspection begins and proceeds simultaneously with slaughtering and carcass-dressing operations. Those carcasses in which disease or other abnormal or questionable conditions are detected and those segregated for slaughter on ante-mortem inspection are given an individual identity by means of special, numbered 'U. S. Retained' tags. All such tagged product is kept under the control of the inspector until final disposition is made of it after a searching examination by skilled veterinarians. It is a requisite that the evisceration of each animal be conducted in the close presence of the inspector. Each set of viscera is examined while the identity of the carcass is maintained. The organs and principal lymph glands are palpated and some are incised. The lungs, liver, lymph glands principally, and the spleen, especially of swine, also the heart and other muscle tissues not infrequently disclose evidence of a serious nature.

"As complete ante-mortem and post-mortem veterinary inspections are essential and form the basis of scientific meat inspection, so is it important under well-ordered meat hygiene that meat previously inspected and passed at the time of slaughter be further inspected and reinspected after it is cut, chopped, mixed, melted, cooked, cured, refined, canned, and otherwise prepared or handled in the same or in another establishment. This is termed product inspection. It begins with the carcass, viscera, fats, and other parts immediately they are passed by the veterinarians conducting the post-mortem examinations and continues until the fresh and prepared products are transported from the establishment.

"In addition to the foregoing inspections of meat and meat food products, the inspectional and investigational work of seven fully equipped laboratories, advantageously located, form an essential part of the Bureau's meat inspection service. The principal purpose of this inspection is to detect in samples collected at all establishments under inspection substances and ingredients not permitted by the regulations in meat or meat foods. In addition, water, ice, spices, and other substances used in the preparation of meat foods are examined for purity.

"The destruction of condemned material is effected by reducing it to denatured grease and tankage, or, at establishments not having facilities for tanking, by effective treatment with crude carbolic acid or other approved denaturant. All condemned carcasses and other condemned material remain in the custody of the inspector until destroyed for food purposes at the same establishment where condemned.

"The marks of inspection are placed on freshly dressed, passed carcasses by marking devices furnished by the Government. A purple, quick-drying, harmless fluid is used. Cans, jars, or other receptacles constituting, within the meaning of the regulations, immediate or true containers of passed product are marked by labels approved by the Bureau. The essential features required on a label are: The true name of the meat or product; a list of the ingredients, where two or more ingredients are used; the name and place of business of the manufacturer, packer, or distributor; an accurate statement of the quantity of contents; and an inspection legend and the number of the establishment at which the product was prepared."

"Since most of the work of the Bureau pertains to veterinary problems, it follows that a large number of its employees are veterinarians . . . skilled . . . in the detection of abnormal conditions in meat producing animals at time of slaughter."

"In addition to its trained veterinarians, the Bureau's personnel includes experienced research workers and specialists qualified to perform the work" connected with the various phases of the Bureau's activities.

2. Technical Sanitation in the Meat Packing Industry

In general, successful food packing operations require the proper control of micro-organisms. An organized program of control of proper sanitation measures has been called technical sanitation. It consists of:

1. The periodic examination of product and equipment by standard bacteriological methods, and comparison of the results obtained in a particular instance with certain standards for the item in question.
2. The application of routine tested methods of cleaning equipment with suitable detergents and/or the sterilization of equipment where necessary, either with chemical antiseptics such as hypochlorite, or by application of heat, usually in the form of steam or hot water.
3. The control of processing temperatures in order to assure control of bacterial growth. This may take two forms: the control of refrigeration temperatures in order to prevent spoilage by controlling the rate of growth of bacteria, or the control of the temperature and times used in smoking, cooking, and canning operations in order to accomplish destruction of bacteria.

A vigorous technical sanitation program is an assurance that bacteria, which may destroy the product before it reaches the consumer, are being controlled. The periodic checkup, which is an important part of such a program, spotlights any hidden abnormalities. The investigational work required in the setting up of the various processing schedules on this basis establishes without question that the processes can accomplish what they are intended to. Technical sanitation as applied to meat packing has been one of the biggest contributions that the food technologist has made.

Chapter XXII

OILS, FATS, AND RELATED PRODUCTS

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I. EXTRACTION OF OILS AND FATS

1. Rendering

The process by which oils and fats are extracted from animal tissues or other materials of high water content is known as "rendering." One feature which is common to all systems of rendering is the application of heat to the fatty tissues to make the walls of fat cells permeable to the water and fat enclosed within them. If the entire rendering operation is carried out in the presence of water, and the water and fat phases are finally separated by gravity, the process is known as wet rendering. If the water is substantially evaporated during the operation, leaving the fat behind it, the process is known as dry rendering. The separation of fat in the frying of bacon is a small-scale example of dry rendering, just as the separation of fat during the boiling of fat meat is an example of wet rendering.

Fatty materials that are to be rendered do not require any great amount of preliminary preparation, although most fatty tissues are chopped into fairly small pieces or "hashed" before being charged to the rendering equipment. In all cases it is necessary to render animal fats as quickly as possible after the animals are killed, in order to avoid excessively high free fatty acids in the fat as the result of enzyme action.

(a) Wet Rendering

Wet rendering¹⁻⁴ may be carried out in a simple open tank equipped with a low-speed agitator and a steam heated jacket. The fatty stock is placed in the tank, water is added, and the contents are heated with gentle agitation until the greater portion of the fat rises in a clear layer to the top of the kettle, where it may be drawn off. If it is desired to have in the fat the blandest possible flavor, as in the preparation of

¹ H. K. Dean, *Utilization of Fats*. Chemical Pub. Co., New York, 1938.

² G. Hefter and H. Schönfeld, *Chemie u. Technologie der Fette u. Fettprodukte*. Springer, Vienna, 1936-1939.

³ T. P. Hilditch, *Industrial Fats and Waxes*. 2nd ed., Baillière, Tindall & Cox, London, 1941.

⁴ H. P. Trevithick and A. P. Lee, *Oil & Soap*, 9, 145 (1932).

oleo stock and neutral lard, the entire operation is carried out at a temperature much below the boiling point of water, and perhaps not greatly above the melting point of the fat. Low-temperature wet rendering is practiced much less now than formerly, as the modern processor is inclined to rely upon deodorizing treatment for the production of bland fats. Rendering at a low temperature does not result in a complete recovery of fat; it is necessary to rework the residues under more drastic conditions to obtain all the fat from them.

Much the greater part of both the lard and edible tallow produced in the United States is extracted by that variation of the wet rendering process known as steam rendering. Steam rendering involves a somewhat prolonged cooking of the charge in closed autoclaves, or digesters, under a steam pressure of 40 to 60 lbs. per sq. in., and at a correspondingly high temperature. Under these conditions, the fatty materials largely disintegrate, and there is a very efficient separation of the fat from them. The lard produced by this process is termed prime steam lard.

(b) Dry Rendering

Dry rendering^{1-3, 5} in its simplest form is conducted in an open kettle similar to that used in low-temperature wet rendering, but with a jacket strong enough to withstand considerable steam pressure. The well-hashed stock is charged to the kettle without the addition of water, and heating and stirring are continued until the charge is substantially dry and its temperature is well above 212° F. The dry residue of connective tissue, etc., or "cracklings," settles to the bottom of the tank. The rendered fat is drawn off from the top. The kettle rendered lard which is produced by this method has a distinctive "cooked" flavor, which is preferred by many to the milder flavor of steam rendered lard.

Open kettle rendering is relatively slow and inefficient, and in addition, subjects the fat to a certain amount of undesirable oxidation as a result of its contact with the air at an elevated temperature. In order to avoid the disadvantages of the open kettle method, a number of closed rendering systems have been devised. The fatty stock is usually agitated or circulated in heated cylinders. After the rendered oil is drained from the cracklings the latter are pressed in hydraulic or screw presses. Vacuum may be applied to the system to protect the oil from oxidation, and to permit the necessary evaporation of water to be conducted at a relatively low temperature.

2. Mechanical Expression

The oil in oil seeds is associated with a much greater proportion of solid material than is that of animal tissues, and is consequently much more difficult to extract. The most commonly employed technique of mechanical expression^{1-3, 6, 7} involves a

¹ R. P. Bennett, *Oil & Fat Industries*, 4, 275 (1927).

² G. Jamieson, *Vegetable Fats and Oils*. A. C. S. Monograph No. 58, Chemical Catalog Co., New York, 1932.

³ W. R. Woolrich and E. L. Carpenter, *Mechanical Processing of Cottonseed*. Univ. Tenn. Press, Knoxville, 1935.

separation of the oil bearing portions of the seed from the other parts, a careful pre-treatment of the separated portions to place them in condition to yield their oil most easily and efficiently, and, finally, expression of the oil by the application of heavy pressure. See pages 582-584.

The process employed in the production of cottonseed oil is typical and therefore is described in some detail. The cottonseed is deprived of its attached fibers in delinters, which are machines similar in principle to ordinary cotton gins. The delinted seeds are decorticated by passing them successively through hullers, which split the seed coat between revolving knife edges, and then through hull beaters, which shake or beat the seed kernel out of the split hull. Separation of the hulls and kernels is effected by an elaborate system of vibrating screens, combined with air separators, or "pneumatic lifts." The separated kernels or meats are rolled between heavy, smooth, steel milling rolls, to form flakes approximately 0.005 inch in thickness. The rolling or flaking operation does not appear to result in any considerable disruption of the fat cells, but merely to make the latter readily accessible to the action of heat and moisture in the subsequent "cooking" operation.

The rolled meats are cooked in a steam heated stack cooker for approximately 1 $\frac{1}{2}$ hrs., during which time their temperature will rise to 225-230° F., or in a pressure cooker, in which the cooking temperature will be in the neighborhood of 260° F. and the cooking time 15-20 minutes. In both types of apparatus, cooking is carried out in the presence of live steam. The cooking treatment coagulates proteins in the cell walls, and makes the latter permeable to the passage of oil. The cooked meats are wrapped in hair cloths, and pressed in a hydraulic press under a pressure of approximately 1800 lbs. per sq. in., to yield crude cottonseed oil. The residue or cake, is utilized as a high-protein animal feed.

In some plants, the expression of oil is carried out in continuous screw presses, or expellers. The preparation of the oil seeds for screw pressing is identical with that for hydraulic pressing, although the plasticity of the seed mass (which is largely determined by its moisture content) is somewhat more critical in the former process.

Oil milling equipment is in general quite flexible and adaptable to varying needs. In the hydraulic mills of the southern United States, for example, both cottonseeds and peanuts are often processed in the same equipment. The hydraulic method of pressing is the older method and is the one largely used in the cottonseed crushing industry. The newer expeller method is in more general use, however, for crushing soybeans.

The methods used for the extraction of olive and palm oils from their oil bearing fruits vary considerably from one factory to another, but may be described in general as combinations of mechanical expression and wet rendering. Basket-type centrifuges are used in some plants instead of presses for the separation of palm oil from the cooked or digested fruit pulp. Olive oil is customarily obtained in a series of pressings, the first of which is conducted under relatively mild pressure and with little or no previous application of heat, to yield the so-called "virgin" olive oil.

3. Solvent Extraction

Even under optimum conditions, mechanical methods of expression produce an oil cake retaining 4-5% of its own weight of oil. If the original oil seeds are relatively low in oil content, a very considerable proportion of the total oil may thus fail to be recovered. By solvent extraction^{1, 2, 8, 9}, the residual oil in the cake may be reduced to 1%, or less, with a corresponding improvement in oil recovery.

The preparation of oil seeds for solvent extraction is similar to that described above for mechanical expression, except that the cooking operation is omitted. It is important that the rolled flakes be both thin and coherent. Oil bearing materials are sometimes extracted by being simply agitated in batch extractors with successive charges of solvent. The efficiency of the process may be somewhat improved by operating a battery of extractors, and carrying out the first extractions of each charge with the miscella, or oil-solvent mixture resulting from previous contacts of oil bearing material and solvent. The greatest efficiency and the most economical operation are obtained, however, only in those systems employing the principle of true counter-current extraction, in which the solvent and the oil seeds make contact with each other in streams moving continuously in opposite directions.

The seed flakes are inclined to disintegrate to some extent under the influence of the solvent, with the formation of fine particles which are difficult to separate from the miscella, and which impede its uniform circulation through the flake mass. Consequently, the mechanical difficulties involved in moving the seeds and the solvent in opposite directions, with free intermixing, are considerable.

The two basic methods of contacting oil seeds and solvent are exemplified by the Bollmann and Hildebrandt systems. The Bollmann extractor has the form of a bucket elevator, and consists of a series of large, perforated baskets which are slowly raised and lowered by an endless chain within a gastight housing. The seeds are contained within the buckets, which are both charged and discharged at the top of the housing. The solvent is introduced in the form of a spray near the top of the system. It percolates downward through the successive buckets on the ascending side of the chain, while a stream of miscella drips in a similar manner through the descending buckets. The finished miscella is drawn off from the bottom of the housing. The Hildebrandt extractor consists of three large tubes arranged in the form of a "U." Perforated screws convey the seeds downward through one leg of the system, horizontally across to the bottom of the second leg, and then vertically up the other leg and above the level of solvent in the latter. The solvent is, of course, pumped in a direction opposite to that in which the seeds move.

Necessary accessory equipment for any system includes meal driers, stripping stills, water separators, and condensers to effect an efficient recovery of solvent from the miscella and from the extracted residue. The entire system must, of course, be closed to avoid fire hazards, occupational diseases, and excessive loss of solvent.

⁸ C. W. Bilbe, *Mech. Eng.*, **63**, 357 (1941).

⁹ W. H. Goss, *Chem. & Met. Eng.*, **48**, No. 4, 80 (1941).

Solvent extraction plants are inherently of such a nature as to be economical only in relatively large sizes. A capacity of 50 tons of oil seeds per day is considered close to the minimum size, and capacities of 100–400 tons are common. Solvent extraction is conducted on a large scale in Europe, but has been relatively little used in the United States, except for the extraction of soybeans. Obviously, solvent extraction is most advantageous in the extraction of seeds of relatively low oil content. Seeds of high oil content are sometimes extracted after being subjected to a preliminary mechanical pressing. Some seeds of high oil content, notably peanuts, disintegrate into a fine flour in the process, and consequently are difficult or impossible to extract by the customary methods.

Petroleum fractions boiling within the range of about 140–185° F. are used almost exclusively as the solvent. Chlorinated solvents are advantageous from the standpoint of fire hazards, but are expensive and are inclined to be somewhat unstable with repeated use. The solvent loss in efficient plants does not exceed 2 gal. of solvent per ton of material extracted.

II. REFINING AND RELATED TREATMENT

1. Alkali Refining

The refining^{1–3, 6} of edible fats and oils is almost always carried out by means of alkalies. The treatment of a crude oil with a solution of alkali not only frees the oil of fatty acids which exist in it in a free form, but also removes a certain amount of other nonoil substances, including phosphatides and various resinous and mucilaginous materials. These substances may be removed by their actual combination with the alkali, by hydration, or by adsorption or occlusion.

Caustic soda in a 12° to 20° Bé. solution is almost invariably used as the refining agent. Animal fats, and oils like peanut oil, which are low in nonoil substances, require an excess of 0.10–0.25% caustic soda (as dry sodium hydroxide, on the basis of the weight of the oil) above the amount required for combination with the free fatty acids. Cottonseed oil, and other resinous or gummy oils, may require an excess of 0.25–0.60%.

The refining operation involves the following successive steps:

- (a) Intimate mixing of the cold oil and the caustic solution to form an emulsion in which the immiscible oil and water phases may interact.
- (b) Application of heat to break the emulsion.
- (c) Separation of the oil and aqueous phases by settling or other means.

Alkali refining will not render an oil completely neutral, but will reduce its free fatty acid content to a negligible value, *i. e.*, 0.01–0.03%. There is a considerable loss of neutral oil in alkali refining, amounting in different oils to 3 to 10 times the weight of the free fatty acids.

(a) Batch Refining

The equipment required for batch refining is relatively simple, consisting essentially of a cylindrical tank or kettle equipped with a two-speed agitator, a cone bottom, and steam heating coils or jacket. The charge of oil at ordinary atmospheric temperature is placed in the kettle, the required amount of caustic soda is added and the batch is strongly agitated for a period usually amounting to 15 min. to 1 hr. The agitation is then reduced, and the batch is heated to about 140–150° F., and held at this temperature until the emulsion “breaks” and the soap stock separates from the clear oil in the form of small flocculated particles. This operation usually requires no longer than 10 to 30 min. Agitation is then stopped, and the soapstock, or “foots,” is allowed to settle into the cone bottom of the kettle.

In the dry refining method, which is generally practiced in the United States and is particularly adapted to the refining of cottonseed oil, the batch is then cooled, and after a period of 10–18 hrs. the oil is drawn off from above the solid or semisolid soap stock. In the wet refining method, which is more generally preferred by European refiners, the oil is heated to 150–170° F. before the alkali is added, and, after reaction is complete, hot water and sometimes dry salt are cautiously added to assist in settling the soap stock and to form with the latter a liquid layer, which may be finally drawn off from the bottom of the tank. This method leaves suspended in the oil a considerable amount of soap solution, which must be removed by a further stage, or further stages, of water washing.

(b) Continuous Alkali Refining

In the United States, the batch refining kettle has been largely superseded by continuous systems,¹⁰ which effect the separation of oil and soapstock by means of centrifugal action, and in which the actual processing time is reduced from a matter of hours to a few minutes. Continuous streams of oil and caustic soda solution are fed through proportioning devices, are thoroughly mixed, and passed first through a heat exchanger heated by hot water and then through a battery of primary centrifuges. The latter continuously discharge soapstock on one side, and oil mixed with a small quantity of soap solution, on the other. The oil is freed of its content of residual soap by mixing it with hot water and passing the mixture through additional batteries of secondary centrifuges. The washed oil is finally dried in a continuous flash drier operating under vacuum.

The continuous, or centrifugal, method allows a very short reaction time between caustic and oil, and effects a very efficient separation of oil and soap stock. Consequently, it avoids the loss of a great part of the neutral oil which is saponified or occluded in the batch process, and at the same time produces an equally good grade of refined oil. The refining losses of cottonseed oil by the continuous process are 20–40% lower than by the batch method.

¹⁰ E. M. James, *Oil & Soap*, 11, 137 (1934).

In the alkali refining process, certain impurities in the crude oils are flocculated and removed as a result of hydration rather than actual combination with alkali. For the removal of such impurities, crude oils are sometimes given a preliminary "water washing" treatment in the centrifugal equipment prior to alkali refining. In this treatment, water or, in some cases, a weak solution of sodium carbonate, trisodium phosphate, or other alkali, is substituted for the caustic soda solution.

2. Steam Refining

Where the object in refining is merely the removal of free fatty acids, this may be accomplished by steam distillation of the relatively volatile acids from the relatively nonvolatile oil. So-called steam refining^{1, 2, 11} is particularly advantageous in the treatment of oils which are quite high in free fatty acids but low in nonoil constituents. With oils of this type, steam refining will effect large savings of oil as compared with alkali refining. Palm oil, for example, with a free fatty acid content of 5% can be steam refined with a refining loss not exceeding 6%. Alkali refining of such an oil will generally result in a refining loss of 15–20%.

An initial steam refining is often employed to reduce the free fatty acid content of the oil to 0.1–0.5%, after which the product is finished by an alkali treatment. Steam refining cannot be used on crude cottonseed oil because, at the high temperatures required, dark-colored pigments are formed which cannot be removed by subsequent alkali refining or bleaching.

Steam refining involves blowing the oil with steam under a vacuum at an elevated temperature (450–475° F.). It is entirely similar, in principle and in operation, to steam deodorization, which will be described in detail in a later paragraph.

3. Bleaching

The refining process leaves some oils quite darkly colored from the presence of oil-soluble pigments which are not readily removed by any chemical means. In such cases, further reduction in color is obtained by treating the oil with surface-active solids which have the power of adsorbing the pigments.^{2, 3, 12, 13} A fuller's earth or bleaching clay is employed, either alone or in combination with a small amount of activated carbon. The amount of earth used is generally 0.5–5.0% of the weight of the oil. If carbon is also used, the customary amount is one-tenth to one-fifth of the weight of the earth.

Bleaching is usually carried out in an open tank equipped with a high- or medium-speed agitator and heating coils or jacket. The oil is heated to 220–240° F., and the bleaching clay thoroughly mixed in. The mixture is then pumped through a filter press, the filtered oil being returned to the tank until its color has reached a minimum value, after which it is diverted to another tank.

¹¹ A. E. Bailey, *Ind. Eng. Chem.*, **33**, 404 (1941).

¹² B. Neumann and S. Kober, *Z. angew. Chem.*, **40**, 837 (1927).

¹³ H. Odeen and H. D. Slosson, *Oil & Soap*, **12**, 211 (1935).

In order to avoid adversely affecting the keeping quality of the oil by subjecting it to contact with the atmosphere at a high temperature, many processors have adopted the practice of bleaching in closed tanks, under vacuum. A continuous vacuum bleaching system has also been devised, which avoids all exposure of the oil to the air until it has been cooled.

Improper techniques in bleaching can do great injury to the stability and consequent quality of edible products. In bleaching, as in all other operations, exposure of hot oil to the influence of air should be avoided or reduced to a minimum, and the use of chemical bleaching agents should be avoided entirely.

There is a slight loss of material in bleaching due to the absorption of oil by the bleaching earth, a loss usually amounting to about one-third of the weight of the earth used.

III. HYDROGENATION

1. Nature of the Process

Hydrogenation¹⁴⁻¹⁷ is the most valuable single process of the oil technologist. The great extent to which the different oils and fats have become interchangeable in the past three decades has been due primarily to the hydrogenation process. By means of this process it is not only possible to use liquid oils as substitutes for plastic fats, but also even to improve on the properties of the natural fats. Chemically speaking, catalytic hydrogenation is a means of reducing the degree of unsaturation of a fat by adding hydrogen to its fatty acid chains at their double bonds. This reduction in unsaturation has the effect of simultaneously increasing the melting point and "hardness" of the fat and its resistance to oxidation. Theoretically, 14.15 cu. ft. of hydrogen at standard temperature and pressure, or about 16 cu. ft. at ordinary temperature, are required to reduce the iodine value of 1000 lbs. of oil by one unit.

For hydrogenation to occur, it is necessary to bring together, at a suitable temperature, gaseous hydrogen, liquid oil, and a solid catalyst. In practice, the hydrogen is dissolved in the oil and the hydrogen-laden oil brought into contact with the catalyst by mechanical means. The rate at which hydrogenation will then proceed will depend upon a number of different factors. The reaction is accelerated by increased temperature although this acceleration is somewhat less than that observed in other chemical reactions in the range of 100° to 300° F. At higher temperatures, the effect of increasing the temperature, is slight, and a maximum reaction velocity is reached at about 400° F. The reaction is also accelerated by increased pressure, or by any other influence which increases the concentration or the rate of solution of hydrogen in the oil. If, as is usually the case, the supply of hydrogen to the oil is sufficient to keep the latter substantially saturated with gas, the velocity of the reaction is more or less pro-

¹⁴ American Chemical Society, Symposium on Hydrogenation, *Ind. Eng. Chem.*, **32**, 1189 (1940).

¹⁵ American Oil Chemists' Society, Symposium on Hydrogenation, *Oil & Soap*, **16**, 24 (1939).

¹⁶ H. K. Moore, G. A. Richter, and W. B. Van Arsdel, *Ind. Eng. Chem.*, **9**, 451 (1917).

¹⁷ A. S. Richardson, C. A. Knuth, and C. H. Milligan, *Ind. Eng. Chem.*, **16**, 519 (1924); **17**, 80 (1925).

portional to the concentration of the catalyst. The reaction proceeds somewhat differently under different conditions of temperature, catalyst concentration, etc., but under most conditions its character approaches that of a monomolecular reaction, the velocity of reaction at any instant being proportional to the unsaturation of the oil.

Because of the fact that oils and fats invariably contain fatty acids of different degrees of unsaturation, hydrogenation may follow a number of different courses. Thus, for example, in the case of an oil containing linolenic, linoleic, and oleic acids, hydrogenation may result in any of the following transformations: linolenic to linoleic acid; linoleic to oleic acid; or oleic to stearic acid. A further complication in the process is due to the fact that the new acids formed are not always identical with the natural acids of a corresponding degree of unsaturation, but are in some cases isomers of somewhat different properties. When linoleic acid is hydrogenated to oleic acid, for example, part of the latter will consist of normal 9,10-oleic acid, but a further part will consist of an isomeric 12,13-oleic acid, which does not exist in nature, and which has a higher melting point than the natural form. The "iso" acids, or new acids of hydrogenation, have not been extensively investigated. By present methods of analysis they are recognized only by their higher melting points and the insolubility of their lead salts in cold alcohol or ether. Although there are undoubtedly a number of different chemical individuals among them, it is customary among hydrogenation technologists to classify them together as "*iso-oleic*" acids.

A third complication in the process arises from the circumstance that hydrogenation may occur alternatively in the α or β positions of unsaturated glycerides. Thus, for example, the saturation of one double bond in α -palmitodiolein may result in the formation of either β -oleopalmitostearin or β -stearopalmitoolein.

2. Factors Influencing the Course of Hydrogenation

In any practical application of the hydrogenation process, the course which the reaction will follow, and the consequent composition of the hydrogenated products, are matters of great importance.¹⁶⁻¹⁸ Most edible oils contain very little unsaturated acids other than oleic and linoleic, and the special and important case of oils of this type has been the subject of a considerable amount of investigation. It has been shown that the process tends to be largely selective, *i.e.*, linoleic acid is converted to oleic acid preferentially to the conversion of oleic to stearic acid, and that normal oleic acid is inclined to be formed somewhat preferentially to "iso-oleic" acid. There are considerable variations in both selectivity and "iso-oleic" acid formation, however, depending upon the conditions under which hydrogenation is carried out.

When hydrogenation is conducted by the ordinary batch process, in which the oil and a dispersed catalyst are heated and stirred together under an atmosphere of hydrogen, it has been shown that the course of the reaction is influenced by the variables of temperature, hydrogen pressure, violence of mixing, catalyst concentration, and

¹⁸ A. E. Bailey, R. O. Feuge, and B. A. Smith, *Oil & Soap*, 19, 169 (1942).

specific nature of the catalyst. Both selectivity and iso-oleic acid formation are favored by a high temperature, a high concentration of catalyst, slow agitation, and low pressure. Some catalysts are more selective than others, and some are more inclined to form iso-oleic acid than others, but the most selective catalysts do not necessarily form the greatest quantities of iso-oleic acid.

The analyses, shown in Table 58, of cottonseed oil hydrogenated to an iodine value of 65 represent typical variations in composition occasioned by moderate variations in the conditions of hydrogenation.

TABLE 58

EFFECT OF VARIATION OF HYDROGENATION CONDITIONS ON THE COMPOSITION OF THE OIL

Sample	Hydrogenation conditions	Percentage composition of fatty acids			
		Saturated	Iso-oleic	Oleic	Linoleic
0	Original oil	26.9	..	27.1	46.0
1	Very highly selective (nickel catalyst)	30.0	20.0	44.5	5.5
2	Highly selective (same catalyst as No. 1)	31.6	13.8	47.4	7.2
3	Moderately selective (same catalyst as No. 1)	33.7	10.4	46.8	9.1
4	Nonselective (same catalyst as No. 1)	38.8	8.2	38.8	14.2
5	Same as No. 3, but different nickel catalyst	34.8	18.4	36.6	10.2

The oils which contain large amounts of highly unsaturated C₂₀ and C₂₂ acids, including whale and fish oil, do not hydrogenate with the same selectivity as those containing only C₁₈ unsaturated acids. In the former oils, the higher molecular weight acids add hydrogen less readily than the C₁₈ acids, and there is a tendency for the latter to become completely saturated even before the C₂₀ and C₂₂ acids are reduced to a single double bond.

In the hydrogenation of edible products, highly selective hydrogenation is generally desirable, since selectivity leads to the maximum elimination of linoleic and other highly unsaturated acids, and this in turn gives maximum stability to the product. In the manufacture of shortenings, a minimum formation of iso-oleic acids is also desired, as the presence of these acids hardens the product, limits the degree to which its unsaturation may be reduced, and consequently limits its stability. In the manufacture of shortening from cottonseed oil, for example, the iodine value of the product may be 60 to 65 if iso-oleic acid formation is reasonably well suppressed, whereas, if it is not, it may not be necessary for the iodine value to be 70 to 75, or higher. In margarine fats, iso-oleic acid is less undesirable, and may, in fact, even be preferred, as its presence in large amounts tends to give to fats the short plastic range natural to butter.

3. Catalysts for Hydrogenation

Platinum, palladium, and nickel are all effective catalysts for the hydrogenation of fatty oils, but, for obvious economic reasons, nickel alone is used in commercial

practice.^{14, 15, 19-21} Since catalytic action occurs only at the surface of the metal, a highly extended surface is obviously required for the catalyst to be active. Consequently, one characteristic held in common by all hydrogenation catalysts is a high degree of dispersion of the metal particles. It must not be supposed, however, that any method of producing highly dispersed nickel will yield an active catalyst. The catalytic action of the nickel is not a function of the entire surface of its particles, but only of a limited number of atoms in the surface. These atoms presumably are able to enter into the reaction because they are to some degree elevated above the common surface of the metal, or are otherwise partially released from the restraining influence of their neighboring atoms. The production of these reactive atoms or "active spots" on a catalyst surface is an exceedingly critical matter, and apparently similar products may vary enormously in the extent to which it is accomplished. Consequently, there are extreme variations in the activities of the catalysts actually used by different oil processors; even the successive batches of catalyst manufactured in a single plant often leave much to be desired in the way of uniformity.

(a) Manufacture of Catalysts

Catalysts are manufactured by various methods^{14, 15, 19, 20} one of which consists of suspending nickel formate in a batch of oil and heating and maintaining the latter at about 460° F. for a period of 1-3 hrs., while a current of hydrogen is bubbled through the oil. Under the influence of the heat, the nickel formate decomposes to form finely dispersed metallic nickel or nickel oxides. The reaction must not be too prolonged, or there will be danger of producing colloidal nickel, which cannot be filtered from the oil. During the operation, the oil in the bath becomes completely hydrogenated. The catalyst may be stored in this oil, or it may be filtered from the hardened oil and resuspended in a liquid oil. This type of catalyst has the disadvantage of being relatively difficult to filter out of the oil in subsequent use, even though admixed with a filter aid.

Another common method of preparation is by precipitating nickel carbonate or hydrate on kieselguhr, or other porous material, and reducing the resulting powder at an elevated temperature in a current of hydrogen. Following are the details of a typical process: 240 lbs. of nickel sulfate hexahydrate is dissolved in 1100 gal. of distilled water and the solution brought to boiling. To the boiling solution is added 60 lbs. of kieselguhr. A fresh solution of 145 lbs. of sodium bicarbonate in 300 gal. of cold distilled water is prepared, and is added uniformly over a period of 1.5 hrs. to the nickel sulfate solution, while the latter is kept continuously and vigorously boiling. An additional 60 lbs. of kieselguhr is then added and the boiling is continued for 0.5-1 hr. longer. At the end of this time, the solution should be slightly alkaline to phenolphthalein. The precipitated catalyst is filtered out, resuspended in 1000 gal. of distilled water, boiled, and refiltered. This last operation is repeated once again, and

¹⁹ H. K. Dean, *Utilization of Fats*. Chemical Pub. Co., New York, 1938.

²⁰ G. Hefter and H. Schönfeld, *Chemie u. Technologie der Fette u. Fettprodukte*. Springer, Vienna, 1936-1939.

²¹ T. P. Hilditch, *Industrial Fats and Waxes*. 2nd ed., Baillière, Tindall & Cox, London, 1941.

the catalyst is then filtered, dried, and ground. It is reduced at 900° F. for 8 hrs. in a revolving, gas heated drum or retort, in a current of hydrogen. After cooling, it is suspended in oil without being permitted contact with the atmosphere.

Nickel sulfate is the cheapest of the soluble nickel salts, but nickel nitrate or chloride is often preferred for catalyst manufacture, as catalysts precipitated from nickel sulfate tend in general to form excessive quantities of iso-oleic acid.

An ingenious variation of the precipitation process, and one which cheaply produces a catalyst of excellent and uniform activity and characteristics, is the method of electrolytic precipitation. In this process, nickel hydrate is prepared by the electrolytic corrosion of metallic nickel in a 1% sodium chloride electrolyte. The anode consists of a nickel sheet. The cathodes consist of two sheets or screens of nickel or other nonrusting material, which are suspended on either side of the nickel sheet at a distance from it of 1.0-1.5 inches. The operation is carried out in a wooden or ceramic tank. The electrolyte, in which is suspended kieselguhr equivalent to the weight of the nickel to be corroded, is stirred and maintained at a temperature of 120 to 125° F. Low-voltage direct current is passed through the cell at a rate sufficient to maintain a current density of approximately 55 amperes per sq. ft. on either side of the corroded sheet. Nickel chloride is formed at the anode; sodium hydroxide is produced at the cathode; and the two combine to produce nickel hydrate and regenerate sodium chloride. The *pH* of the solution in the cell is highly important, and must be maintained at 9.25 (± 0.2). The tendency of the solution to become alkaline, from the formation of basic nickel chloride, is compensated for by the constant addition of gaseous carbon dioxide, which also has a desirable buffering action. At the end of the precipitation period, the catalyst is filtered, washed free of sodium chloride with distilled water, dried, ground and reduced at 800° F. for 3 hrs.

A third method of preparing catalysts, the Raney, or nickel alloy method, consists of alloying metallic nickel with aluminum and dissolving out the aluminum from the powdered alloy with sodium hydroxide solution. The resulting nickel dispersion is washed free of caustic by repeated boiling with water, followed by decantation; after the water in the wet sludge is replaced by oil, the catalyst is ready for use.

As may be expected from their characteristic structures, all catalysts are somewhat sensitive to heat, and may be sintered and rendered inactive by temperatures much below the melting point of massive nickel. Supported catalysts of the precipitated type may normally be heated to 900° to 1000° F. in the process of reduction, without harm, however. All catalysts are extremely pyrophoric when freshly prepared, and must not be exposed to the air or other source of oxygen without a protective coating of oil.

(b) Catalyst Poisoning

The active atoms of a catalyst will readily combine with a variety of reactive substances, with consequent inactivation of the catalyst. Since only a small portion of the total metal in a catalyst is active, a very small amount of reactive substance may have a relatively great effect on the activity of the catalyst. The process by which

small amounts of certain substances diminish or destroy the activity of a catalyst is known as catalyst poisoning. Many different substances are catalyst poisons, but those of greatest concern to the hydrogenation technologist are most commonly found in commercially produced hydrogen, namely, the gaseous sulfur compounds (hydrogen sulfide, sulfur dioxide, carbon disulfide, carbon oxysulfide, and carbon monoxide.)

The poisoning effect of the sulfur compounds is irreversible, but that of carbon monoxide is reversible, and hence carbon monoxide may be more properly called a catalyst paralyzer. Subjection of the hot oil and catalyst mass to a moderately high vacuum releases the combined carbon monoxide and completely restores the activity of the catalyst. The paralyzing effect of carbon monoxide is much more pronounced at the lower temperatures of hydrogenation, hence it is particularly troublesome in the hydrogenation of products at low temperatures to avoid the formation of iso-oleic acid. At 400° F. and above, its effect is but slight. The amount of sulfur or other poison required to inactivate a catalyst is in direct proportion to the activity of the latter. Good catalysts will absorb sulfur to the extent of 3-5% of their content of nickel before being completely inactivated.

Even well-refined oils of good quality contain small concentrations of organic poisons which eventually inactivate a catalyst with repeated use. Oils produced from badly damaged materials, and particularly fish oils, may poison the catalyst rapidly.

4. Hydrogen Production

Most of the hydrogen used in the hydrogenation of oils and fats is produced either by the electrolytic or the steam-iron process.^{20, 22, 23} The electrolytic method involves a simple electrolysis of an electrolyte, usually sodium hydroxide solution, by a direct current to yield hydrogen and oxygen. This method has the advantage of producing hydrogen of a high degree of purity, but is economical only in regions where electric power is relatively cheap, as the requirements of the latter for electrolysis are not less than about 125 kw.-hrs. for each 1000 cu. ft. of hydrogen produced.

In the steam-iron process of hydrogen manufacture, hydrogen is produced by blowing a mass of hot iron ore alternately with steam and a reducing gas. The process is entirely similar in principle to the familiar "gun barrel" experiment of inorganic chemistry. The iron oxide is alternately reduced and oxidized; in the oxidation portion of the cycles, relatively pure hydrogen is formed from the reduction of water vapor. Pure hydrogen is, of course, not used for reduction. The reducing gas is ordinary blue gas, produced by the action of steam on hot coke, and consisting largely of hydrogen and carbon monoxide.

(a) Equipment

In the United States, the hydrogen generator most commonly employed is of the Bamag type. This consists of a single tall cylinder or retort, several feet in diameter,

²² S. Hurst, *Oil & Soap*, 16, 29 (1939).

²³ H. S. Taylor, *Industrial Hydrogen*. A. C. S. Monograph No. 4, Chemical Catalog Co., New York, 1921.

lined with refractory material, in which is supported a mass of specially porous and reactive iron ore. Directly above the ore chamber and connected with it is a steam superheating chamber which is filled with a checkerwork of firebrick to give a large heat capacity. The flow during the steaming phase is from the top to the bottom of the generator, while that during the reducing phase is in the opposite direction. During the reducing phase, air is admitted at the bottom of the superheater. The combustion of blue gas with this air serves to heat the steam superheater for the subsequent steaming phase, and to maintain the system at the proper reaction temperature, which is usually in the range of 1200° to 1500° F. Air is also blown downward through the ore mass for a short period during each cycle, to burn off accumulations of carbon deposited in it from the decomposition of carbon monoxide. A generator of the size most commonly used has a nominal capacity of 5000 cu. ft. of hydrogen per hour. In practice, this capacity is usually exceeded somewhat.

The Lane multiretort system is also quite commonly used. In this system, the ore mass is contained in a number of small generators, rather than one large one, and the retorts are heated externally, rather than internally, by the combustion of blue gas. In Europe, the Messerschmitt system is often used. The Messerschmitt generator, like the Bamag, consists of a single retort, but the steam superheater is centrally located, and the ore is contained in an annular space between the superheater and the shell.

Equipment required for a complete steam-iron plant includes, in addition to the hydrogen generator proper, a blue gas generator, a source of steam, gas holders for both blue gas and hydrogen, a water scrubber and cooler for the crude hydrogen, a blower for supplying blue gas to the generator under slight pressure, a hydrogen compressor, high-pressure storage tanks for the finished hydrogen, and equipment for purifying the crude hydrogen.

In the most efficient steam-iron plants, 1.5-1.7 cu. ft. of blue gas is required to produce 1 cu. ft. of hydrogen. This corresponds to a coke consumption for blue gas manufacture of about 50 lbs. per 1000 cu. ft. of hydrogen.

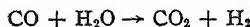
(b) *Purification of Hydrogen*

Crude, water-scrubbed, steam-iron hydrogen will usually contain the following impurities: carbon dioxide, 0.5 to 1.0%; carbon monoxide, 0.2 to 0.5%; nitrogen, 0.5 to 1.0%; hydrogen sulfide, 0.05 to 0.15%; and organic sulfur compounds, 0.1 to 0.5 grain per 100 cu. ft. Carbon dioxide and nitrogen are inert in the hydrogenation reaction, and merely serve as diluents in the hydrogen; the other impurities are catalyst poisons and must be removed before the hydrogen is used.²³

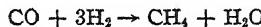
The bulk of the hydrogen sulfide and carbon dioxide are usually removed by absorption in scrubbing towers of the packed or bubble-cap types. In some plants, the alkali used for absorbing these impurities consists of caustic soda solution; in others, their removal is effected more economically by monoethanolamine, which possesses the advantage of being easily regenerated, after it is spent, by the simple application of heat and stripping steam.

Traces of hydrogen sulfide remaining after alkali scrubbing are removed by absorption in iron oxide supported on wood shavings, in purifying boxes similar to those in common use in the manufactured gas industry. Organic sulfur compounds are not absorbed by iron oxide at ordinary temperatures, but are readily taken up at 175–400° F., in the presence of a small amount of water vapor in the hydrogen.

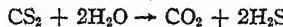
Carbon monoxide is most commonly removed by the so-called water gas-catalytic process, wherein the hydrogen is mixed with steam and passed over a metal oxide catalyst at a temperature of about 850° F., to form carbon dioxide and hydrogen,



An alternative purification process is that of methanation, which involves passing the hydrogen over a nickel catalyst maintained at 575–600° F. Carbon monoxide and hydrogen interact to form methane and water, according to the following equation:



The water gas-catalytic process has the advantage of causing no loss of hydrogen, but does not effect a complete removal of carbon monoxide, since an equilibrium is reached after conversion is about 90–95% complete. The methanation process removes carbon monoxide completely; but in the operation three volumes of hydrogen are lost for each volume of carbon monoxide in the impure hydrogen. In many installations the two processes are combined, with the water gas-catalytic process being employed for the removal of the bulk of the carbon monoxide, and the remainder being removed by methanation. In the water gas-catalytic process, organic sulfur compounds are converted to hydrogen sulfide:



which is scrubbed out with the carbon dioxide formed. If the methanation process of purification is used, organic sulfur compounds must be rigorously removed by heated iron oxide before the hydrogen is passed to the methanator, in order to avoid rapid poisoning of the methanation catalyst.

5. Batch Hydrogenation

Hydrogenation is usually carried out by the batch process.^{24, 25} The equipment used is relatively simple, consisting of a closed, vertical, cylindrical steel vessel capable of withstanding moderate pressure. The vessel is equipped with an agitator and closed heating and cooling coils.

The various elaborations that have been introduced in the equipment by different

²⁴ American Chemical Society, Symposium on Hydrogenation, *Ind. Eng. Chem.*, **32**, 1189 (1940).

²⁵ American Oil Chemists' Society, Symposium on Hydrogenation, *Oil & Soap*, **16**, 24 (1939).

users have had as their principal object the promotion of better mixing of the hydrogen and the oil. The agitation desired is of a somewhat different nature from that employed in most processes, since the object is not actual mixing of the liquid, but rather the establishment of a large interface between the gas and the oil in order to hasten solution of the hydrogen. The hydrogen is injected at the bottom of the tank and allowed to bubble up through the body of oil. The surface of the bubbles form a considerable part of the total gas-oil interface. In order to maintain this bubbling at a maximum, some processors continuously withdraw hydrogen from the head space of the vessel and recirculate it through a blower to the bottom. One manufacturer of mixing equipment avoids the use of external circulation by employing a turbine-type stirrer with a suction sleeve extending into the head space of the vessel. This device continuously circulates hydrogen within the vessel by drawing it from the head space into the housing of the stirrer. Turbine-type stirrers, especially built for gas diffusion, are the most satisfactory type of agitating equipment.

In any type of equipment, in order to avoid excessive power costs, the power input should be directed largely toward dispersion of the gas rather than movement of the liquid. Systems have been devised in which the oil and catalyst mixture is sprayed into a hydrogen-filled chamber, with continuous recirculation of the liquid, but such systems are more complicated than the simple batch apparatus and possess few, if any, compensating advantages.

Hydrogenators usually have a capacity of 10,000 to 25,000 pounds of oil. They are commonly operated at a gage pressure varying between 5 and 60 lbs. per sq. in., and at a temperature between 150 and 400° F. The amount of catalyst used may be as little as 0.01% (in terms of nickel, on the basis of the weight of the oil) or as much as 0.2 or 0.3%, but the usual amount is between 0.05 and 0.10%. The characteristics desired in the product will determine the conditions of hydrogenation and particularly the temperature employed. For the production of vegetable stearine or other highly hydrogenated products, the matter of composition is unimportant and the operation will probably be conducted at a temperature of 350-400° F. If iso-oleic acid must be kept low, however, as in the manufacture of all-hydrogenated shortenings, a temperature in excess of 250 or 300° F. will seldom be employed. Sometimes it is advantageous to conduct the hydrogenation in two steps, each at a different temperature.

The following is a typical sequence of operations in the preparation of a shortening of the all-hydrogenated type: An hydrogenator of 20,000 lbs. capacity is charged with refined and bleached cottonseed oil and 0.08% of nickel (catalyst). The charge is heated under a vacuum, with stirring, to a temperature of 170° F., and then placed under a hydrogen pressure of 50 lbs. gage. Hydrogenation is continued under these conditions until the iodine value of the oil is reduced to about 75. The hydrogenation is then interrupted by releasing the pressure in the hydrogenator and placing the charge under vacuum until its temperature has been raised to 260° F. The charge is again placed under a hydrogen pressure of 50 lbs., and hydrogenation is continued until its iodine value is about 62, or until analysis of the oil by a quick penetration technique shows its consistency to be at the proper value. Hydrogenation is then halted by

again placing the charge under vacuum while it is cooled to 150° F. The vacuum is then released and the charge is pumped through a filter press to remove the catalyst. The composition of the fatty acids of the product will be approximately as follows: Saturated acids, 33%; iso-oleic acid, 10%; oleic acid, 52%; and linoleic acid, 5%. The total hydrogenation time will usually be 2 to 4 hrs.

6. Continuous Hydrogenation

The Bolton-Lush continuous hydrogenation process was developed in England and is said to have attained some use in that country.²⁶ The catalyst used in this system consists of massive nickel turnings which have been rendered catalytically active by a special "anodic oxidation" treatment. The oil flows continuously downward over the stationary catalyst, which is maintained in a heated condition in an atmosphere of hydrogen. This process is very much less selective than the batch process, and hence does not appear well adapted to the manufacture of edible products. Continuous systems utilizing a powder catalyst, with centrifugal separation of catalyst and oil, have been proposed, but do not appear to have been used commercially.

IV. FRACTIONAL CRYSTALLIZATION

In some cases, oils and fats can be better utilized after some degree of separation of their higher- and lower-melting components. This is accomplished by subjecting the molten fat to a sufficiently low temperature to bring about partial crystallization, and then separating the liquid and solid portions by filtration or pressing.

Fractional crystallization is practiced commercially in the production of oleo oil, and in the "winterization" of cottonseed and other vegetable oils. In the treatment of oleo stock the process serves the double purpose of producing a low melting oleo oil which can be used for the manufacture of margarine and similar purposes, and producing a high melting oleostearine, which is suitable for stiffening liquid oils to a lard-like consistency. Cottonseed oil, because of its relatively high saturated acid content, becomes solid or semisolid at domestic refrigerator temperatures of 40–50° F. In order to produce an oil which is liquid under such conditions, cottonseed oil is subjected to fractional crystallization on a large scale.

1. Manufacture of Oleo Oil

Only fresh, selected, internal beef fats are used in the preparation of oleo stock. These fats are chilled, washed well, and rendered at a low temperature. The resulting oleo stock is charged in melted form into small, rectangular tanks holding about 600 lbs. each, and which are mounted on trucks. The tanks of oil are held in a room maintained at a temperature in the neighborhood of 90° F. for several days, until the

²⁶ E. R. Bolton, *J. Soc. Chem. Ind.*, **46**, 444T (1927).

desired degree of crystallization has taken place. It is important that the crystallization, or graining, take place slowly, in order that the resulting crystals will be large and easily separated from the liquid oil. Rapid cooling will yield a product containing many small crystals, difficult or impossible to separate from the entrapped oil. After crystallization is completed, the pasty, liquid-solid mass is wrapped, in portions of a few pounds each, in canvas cloths, which are stacked in a press of the plate type. Moderate pressure is applied to the press to yield oleo oil and residual cakes of oleostearine.

The oleo oil is light yellow in color and has a mild and pleasant flavor. Its iodine value is not greatly higher than that of ordinary tallow, being usually 44 to 48. Its plastic range is very short; it will be quite hard, and even brittle at 40-50° F., but completely melted at 90-95°. The stability of oleo oil will vary greatly with the care used in its manufacture, but will usually be between 15 and 30 hrs. by the Swift method. See page 578, Volume I. A frequent cause of poor keeping quality is the use of improperly laundered press cloths.

Oleo oil is usually packaged in steel drums and sold as an ingredient of margarine, as a confectionery fat, or as a shortening agent for commercially baked biscuits, crackers, etc. For use by confectioners and bakers, a plastic oleo oil is sometimes prepared by the same methods as those used for solidifying shortenings.

Oleostearine is almost white in color, as the pigments of the original stock are largely concentrated in the liquid fraction. It is used in the manufacture of blended types of shortenings, in the ratio of about 20 parts to 80 parts of liquid oil, and also in the manufacture of margarine of the puff paste type, in the ratio of about 35 parts to 65 parts of oil.

2. Manufacture of Winterized Salad Oils

Early in the history of the manufacture of edible cottonseed oil, it was observed that oil drawn from the tops of tanks which had stood out of doors through the winter was not inclined to solidify or deposit "stearine" when artificially cooled. The oil thus obtained was termed "winterized," and the term was retained after the demand for the product made it necessary to employ artificial winterization in its manufacture.

The winterization²⁷ of cottonseed oil is carried out as follows: The entire operation is conducted in a refrigerated room, cooled to 40-45° F. The design of the crystallizing tanks varies considerably in different establishments. In some plants, the tanks are constructed in a very narrow form (2 to 3 ft. in width) and refrigeration is supplied to the oil through the cold air of the room. In others, the tanks are of conventional shape and size (10,000-30,000 lbs. capacity each) and are equipped with cooling coils through which refrigerated brine is circulated. In any case, it is essential that the rate of cooling be very slow and that agitation of the oil be avoided in order that the

²⁷ A. P. Lee, *Oil & Soap*, 16, 148 (1939).

separated crystals may be large and rigid enough to be filterable. Even under the most favorable conditions, filtration of the cold, viscous oil from the relatively non-rigid crystals is a slow and relatively difficult matter; and carelessness in forming the crystals may easily lead to complete failure of the operation.

If cooling coils are used in the tank, a refrigerant is generally not expanded directly in them; they are cooled with brine, and it is desirable to have the refrigeration system so designed that the temperature of the brine will be easily variable. A temperature differential between brine and oil varying from about 30° F. when the oil is at 75°, to about 10° when the oil is at 45°, is usually satisfactory. The cooling coils should be closely spaced in the tanks, as mechanical stirring of the oil cannot be permitted during the chilling process.

The oil is usually charged to the chilling tanks at a temperature of 70–80° F. It may then be cooled to a temperature of about 55° in 6 to 12 hrs. At this temperature the first crystals usually begin to form. The cooling rate is then reduced somewhat, and an additional 12 to 18 hrs. is allowed for the temperature to drop to about 45°. The rate of crystallization will then be sufficiently rapid to cause a slight rise in the temperature of the oil, even though the refrigeration input is maintained at a constant level. The temperature will rise usually 2–4°, and then drop, as before. When it has dropped to a point slightly below the previous minimum (*e. g.*, to 42°) the cooling is arrested, and the oil is held at this temperature for 12–14 hrs. It is then filtered. A considerable amount of crystallization takes place during this latter holding period, and the degree of winterization obtained will depend more upon the length of this period than upon the final temperature.

Filtration is usually carried out in an ordinary plate-and-frame, or recessed-plate filter press. A low-speed positive displacement pump is sometimes used for forcing the oil-crystal mixture through the presses, but the preferred practice (to avoid breaking up the crystals) is to drop the oil from the chillers by gravity into closed tanks or "eggs," from which it is forced through the press with compressed air. Filtration is relatively slow, as it must be conducted at a low pressure (5–20 lbs. gage). The application of high pressure has the effect of compressing the filter cake and making it impermeable to the passage of oil. The usual time required for both crystallization and filtration of a batch is 3 to 6 days.

From a cottonseed oil with an iodine value of 107, prepared as above, the average yield is about 65% of an oil with an iodine value of 113, and 35% of cake with an iodine value of 95. The cake is liquid at ordinary temperatures and, unlike oleostearine, has no "stiffening" effect on liquid oils. It is used more or less interchangeably with ordinary cottonseed oil in the manufacture of other edible products.

A minimum cold test of 5.5 hrs. is specified for the manufacture of mayonnaise, but most winterized cottonseed oils have a test of 8 to 16 hrs. The use of lecithin as a crystallization inhibitor for salad oils has been patented. A sample of winterized cottonseed oil which at 32° F. becomes cloudy in 10 hrs., semisolid in 32 hrs., and solid in 48 hrs. will, with the addition of 0.05% of soybean lecithin, require about 15 hrs. to cloud and 150 hrs. to become semisolid.

V. DEODORIZATION

1. Steam Deodorization

The process universally used for removing odor and taste from edible oils is steam deodorization.²⁸⁻³¹ The principle upon which this process operates is that of vacuum steam distillation. At the high temperatures employed, the odoriferous compounds of the oil become sufficiently volatile to be stripped out, by a current of steam, from the relatively nonvolatile oil. The application of reduced pressure during the operation greatly reduces the amount of steam required, prevents undue hydrolysis of the oil by the steam, and protects the hot oil from atmospheric oxidation.

The compounds responsible for taste and odor have not been individually identified, but probably consist variously of aldehydes, ketones, hydrocarbons, and essential oils, to the amount of perhaps 0.10% of the weight of the oil. Each kind of oil has, of course, its more or less individual and characteristic compounds. Because deodorization, if properly carried out, will result in practically complete removal of these substances, well-deodorized oils of different kinds are indistinguishable one from the other by taste or odor.

Deodorization also destroys any peroxides in the oil and removes any volatile products of rancidity, so that rancid oils can be apparently reclaimed by the process. Such oils easily become rancid again, however, apparently because of the destruction of antioxidants during the process of their initial spoilage.

The uncombined fatty acids are also relatively volatile; consequently, any free fatty acids in the oil will be largely removed by deodorization. The process may also be applied with the removal of fatty acids as its primary object, in which case it is termed "steam refining." The free fatty acids of an oil cannot ordinarily be reduced below about 0.01–0.02%, however, since the stripping steam has a slight tendency to split the oil with the formation of free fatty acids. Because the ratio at which the fatty acids are distilled is proportional to their concentration in the oil, a point is eventually reached at which the rate of their removal is equaled by the rate of their formation.

(a) Equipment for the Batch Process

Deodorization²⁸⁻³¹ is usually carried out in closed, vertical, cylindrical steel vessels, with cone or dished bottoms. The usual capacity is 15,000–30,000 lbs. The injection of steam into the vessel while the latter is under vacuum results in considerable movement and splashing of liquid; several feet of head space must be allowed above the surface of the liquid to prevent entrainment of oil with the steam. Spray separators of the louvre type are often installed in the upper part of the vessel.

Vacuum is usually supplied by a multistage steam ejector system. For most favor-

²⁸ H. K. Dean, *Utilization of Fats*. Chemical Pub. Co., New York, 1938.

²⁹ G. Heftner and H. Schönfeld, *Chemie u. Technologie der Fette u. Fettprodukte*. Springer, Vienna, 1936–1939.

³⁰ T. P. Hilditch, *Industrial Fats and Waxes*. 2nd ed., Baillière, Tindall & Cox, London, 1941.

³¹ A. E. Bailey, *Ind. Eng. Chem.*, 33, 404 (1941).

able operation, the vacuum equipment must be capable of maintaining an absolute pressure on the vessel not in excess of $\frac{1}{4}$ in., or 6 mm., of mercury. To obtain a vacuum this low, at least three stages of compression are required. Surface condensers easily become fouled by the accumulation of fatty material carried by the steam; for this reason, intercondensers of the barometric type are used in connection with the steam ejectors. The primary thermocompressor, or ejector, is usually placed directly over the vapor opening from the top of the vessel and as close as possible to the vessel in order to minimize any tendency for the reflux of volatile materials.

Steam ejector vacuum equipment is not flexible in operation, and for the greatest efficiency and economy must be designed to maintain a definite pressure and handle a definite quantity of injected steam. Steam will, of course, be injected at the maximum rate possible without undue entrainment of oil. For deodorizers of 20,000–25,000 lbs. capacity, operating under a vacuum of $\frac{1}{4}$ in., a suitable rate is 300–350 lbs. per hr. For compressing 300 lbs. of injected steam, the steam ejectors will require 900–1200 lbs. of steam for operation, making the total steam requirements of the process 1200–1500 lbs. per hr. Steam ejectors are usually designed to operate at 90–125 lbs. gage pressure.

Some form of distributor must be provided in the bottom of the deodorizer for breaking up the stream of injected steam, but elaborate diffusing devices are unnecessary if the body of oil in the deodorizer is reasonably deep (4–8 ft.).

Formerly, when vacua used in deodorizing were low and injection steam requirements were correspondingly high, it was the usual practice to superheat the injected steam to prevent it from unduly cooling the batch of oil. In modern practice, where vacua are high and steam requirements low, superheating of the injected steam is more or less unnecessary and is often omitted.

For rapid and complete deodorization, the operating temperature must be at least 400° F., and should preferably be 425° to 475°. Special equipment must be provided for heating the oil to this high temperature, which is considerably above that of steam at ordinary pressures. In one heating system, the oil is heated directly by circulating it through direct-fired heaters. In another heating system, it is heated directly by circulating a mineral oil through heaters and then through coils in the deodorizer.

High-pressure boilers and steam compressors have also been used for attaining high steam temperatures. The most recent and most satisfactory system, however, employs a closed system with a special boiler in which water is replaced by a high-boiling diphenyl-diphenyl oxide mixture (Dowtherm). This material boils at 500° F. at atmospheric pressure and consequently does not require high pressures for a high vapor temperature. The vapors from the boiler are condensed in coils in the deodorizer body in precisely the same way that steam is condensed in ordinary process heating. The deodorizers are commonly elevated considerably above the ground level to permit barometric condensers to be used with the steam ejectors. When they are so located, simple gravity return can be used for returning the condensate to the boiler.

For cooling the batch of oil after deodorization is complete, water may be passed through a separate set of coils in the deodorizer, cooled liquid diphenyl-diphenyl

oxide may be circulated through the vapor coils, or the hot oil may be pumped out of the deodorizer through a water-cooled heat exchanger.

(b) *Operation of the Batch Process*

The deodorization²⁸⁻³¹ of an edible oil or fat is carried out as follows: The batch of oil is pumped into the deodorizer and the vacuum producing equipment is immediately placed in operation. Heat is then placed on the heating coils. During the first part of the heating period only enough steam is injected to keep the batch stirred; after the temperature has risen to 200-225° F., the steam flow is increased to its normal value.

The rate at which the stripping steam may be injected without blowing oil out of the deodorizer will depend upon the vacuum, and must be determined by actual test. Ordinarily, the proper steam flow for a 20,000-lb. batch under $\frac{1}{4}$ -in. pressure is about 300 lbs. per hr. The steam flow must, of course, be accurately measured and controlled. This is most easily accomplished by maintaining a definite and constant steam pressure on the high side of a metering nozzle in the injection line.

The batch is then raised as quickly as possible to the operating temperature, and steaming is continued for a period of time sufficient to effect complete deodorization. The time required will depend upon the temperature, and must be determined for each product and each separate installation by experience. The time required for complete deodorization of cottonseed oil will normally be found to be approximately as follows: at 350° F., 16 hrs.; 375°, 9 hrs.; 400°, 5 hrs.; 425°, 2.75 hrs.; 450°, 1.5 hrs.; 475°, 1 hr.; and 500°, 0.5 hr.

Oils may usually be heated to 475°, 500°, or even 525° F. without injury, although most operators prefer to deodorize at some temperature between 425 and 475°.

After deodorization is complete, the oil may be either pumped out of the deodorizer through a water-cooled heat exchanger, or cooled within the deodorizer by suitable means. In either case, the deodorized oil should not be permitted to have contact with the atmosphere until it has been cooled to 120-140° F. It is also preferable to continue the injection of steam at a reduced rate while the oil is being pumped out of the deodorizer, or during most of the cooling period if it is cooled within the deodorizer.

Extreme care must be taken to protect the batch of oil from access to air at all stages of the operation, as contact of the oil with oxygen at elevated temperatures is highly injurious to both its keeping quality and its flavor. The deodorizer and its fittings should be welded wherever possible, and all valves, etc., should be kept absolutely tight. Particular care should be exercised in cooling the charge and removing it from the deodorizer after deodorization is complete, because faulty operation at this stage of the process may easily ruin the flavor and quality of otherwise well-deodorized oil. Further heating and handling of the oil after it has been deodorized should be avoided as much as possible. In the best operated plants, all edible fat and oil products are packaged and ready for shipment within a few hours or even minutes after they have come out of the deodorizer.

A certain loss of material must be incurred in deodorizing from the removal of odoriferous compounds and free fatty acids, and from some slight distillation of neutral oil. In general, the total loss should not exceed about 0.5%.

2. The Continuous Process

Continuous steam refining has been practiced for some time in Europe. Recently, a continuous deodorization process³² was developed and successfully applied in a number of plants in the United States. In this process, the heated oil flows down a tower fitted with trays and bubble caps, countercurrent to the stripping steam. Application of the principle of countercurrent flow makes the action of the stripping steam very efficient and effects considerable savings in charges of steam and condensing water. A saving in heat is likewise effected by using the hot oil issuing from the tower to pre-heat the feed oil. Units have been installed with capacities as high as 5000 lbs. per hr.

VI. MISCELLANEOUS OPERATIONS

1. Solidification of Plastic Products

An essential feature of lard, shortening, margarine, and similar products is their plasticity.^{28, 29, 33} Technically speaking, a solid is plastic when it will resist deforming stresses entirely up to a certain value, but will give way if this value is exceeded. Thus the products mentioned have no tendency to flow, but can be readily mixed or spread.

Fats owe their plasticity to the fact that they consist of a mixture of liquid oil with solid crystals. If the latter are sufficiently small in size, the oil is firmly bound to them by its surface tension, and there is little or no tendency for the liquid and solid portions to separate. The ability of the fat to withstand deforming stresses is due to the tendency of the solid crystals to "clot" or interlock.

In order to insure a fine crystal structure and the proper plastic properties in edible fat products, it is essential that they be chilled rapidly as they are solidified. This was formerly accomplished in most cases by the use of a chill roll, which consists of a large, slowly revolving, horizontal steel cylinder, refrigerated internally by brine or direct expansion of a refrigerant. A single roll has a capacity of about 10,000 lbs. of fat per hr. The cold roll picks up an external coating of liquid fat at 110-130° F. from contact with a trough filled with this material. After the fat has been in contact with the roll for slightly less than one revolution it is removed by a scraper blade and deposited in an open trough, or picker box, equipped with a screw conveyor. The temperature of the fat at this point is usually 65-75°. If air is to be emulsified with the finished product, a portion of the conveyor shaft is equipped with blades which whip air into the

³² D. K. Dean and E. H. Chapin, *Oil & Soap*, 15, 200 (1938).

³³ L. I. Dawson, *Oil & Soap*, 10, 51 (1933).

solidified fat. In order to impart to shortenings a white, creamy appearance it is customary to incorporate air amounting to 6-15% of the volume of the fat. The amount of air mixed into lard is somewhat less, usually amounting to 3-6%. From the picker box, margarine is conveyed to blenders for treatment which will be discussed in a later paragraph. In the solidification of shortening and lard, the fat is conveyed to a high-pressure steam pump, which places it under a pressure of 400-500 lbs. per sq. in. The fat is then homogenized by being forced through a constriction or system of constrictions under this high pressure. Various homogenizing devices are used, including orifices, slots, screens, and valves, but all have as their object the dispersion or breaking up of any aggregates of material by the application of intense shearing forces. Some manufacturers pass their products through several repeated stages of homogenization. After the final stage of homogenization, the product is finished and is discharged directly into packages.

In recent years, the roll system of solidification has been supplanted to a considerable extent by the closed or votator system, in which the entire operation is conducted out of contact with the atmosphere. In the votator, the chilling operation is carried out inside a small refrigerated cylinder equipped with sharp, fast revolving, scraper blades. The shaft carrying these blades is relatively large in diameter, so that the flow of fat in the cylinder is through a narrow annular space, very close to the refrigerated cylinder walls. The rotation of the blades causes them to bear lightly against the walls. Their continual scraping action results in an extremely high rate of heat transfer, and enables the unit to be built very compactly. The melted fat is delivered to the chilling cylinder by a small, high-pressure rotary pump which maintains a pressure in the neighborhood of 300 lbs. on the system. Any air or inert gas that is to be emulsified in the shortening is metered into the suction of the pump. The amount of air added can thus be very accurately controlled, and an inert gas such as nitrogen can be substituted for air, if desired.

From the chilling cylinder, the fat is passed into an auxiliary cylinder, unrefrigerated, but equipped with stirrer blades. Cooling is so rapid in the chilling unit that the fat issuing from it is in a considerably supercooled and only partly crystallized condition, although the temperature may be 65-75° F. The auxiliary, or B unit, serves to maintain the fat in a condition of agitation until crystallization is largely completed. If the product is filled into containers while it is still supercooled, and allowed to crystallize in a static condition, it will be excessively hard, possibly due to the formation of a latticework in which the crystals are actually joined together, rather than merely interlocked. From the B unit, the fat passes through an homogenizing valve to a high-pressure steam pump, and from this point the handling of the product is identical with that described above in connection with the chill roll.

The closed system has obvious advantages over the roll system in ease and positiveness of control. It also avoids another undesirable feature of the older method, namely, the exposure of a large refrigerated surface to the atmosphere. This results in a considerable saving in refrigeration, and prevents moisture from entering the product by condensation from the air.

2. Margarine Manufacture

Margarine,^{28-30, 34} like butter, is an emulsion consisting of an internal aqueous phase enclosed in an external phase of plastic fat. The essential materials for margarine manufacture are milk, salt, and a suitable fat. Skim milk is usually employed. The milk is pasteurized and then inoculated with a starter or special culture of lactic acid and flavor producing bacteria. It is then allowed to sour, or ripen, over a period of 12 to 24 hrs., at a temperature of about 70° F.

The ripened milk and the melted fat are placed together in a tank in the proper proportions and are mixed or churned, to produce a fairly intimate mixture of the fatty and aqueous phases. A number of different methods are used to solidify this mixture or emulsion. Formerly the most common practice was to run it in a thin stream into a trough filled with flowing ice water. The solidified fat floated to the surface in flakes or chunks, which occluded considerable amounts of this cooling water. The flakes were skinned off and the excess water was worked out by a kneading process in a special machine. Obviously, this method resulted in washing out a portion of the milk, and produced a margarine with a more or less uncertain moisture content. In most plants, margarine is now solidified on rolls or in votators similar to those used for the solidification of shortening.

The homogenization of the solidified margarine is carried out somewhat differently from that of shortening. In general extreme homogenization is not desired, since it leads to such a fine dispersion of the aqueous phase that the product will resemble shortening in appearance rather than butter. Consequently, the product after solidification is subjected only to a mixing and kneading action in a worker, or blender, which may be of any one of a great number of different designs. The required amount of salt, in finely flaked form, is also worked in at this stage. It is preferable to allow a period of 12-24 hrs. to elapse between solidification of the milk-fat mixture and addition of the salt because the full flavor of margarine is developed by bacterial or enzyme action only after the milk has been in contact with the fatty phase, and this action is inhibited by the presence of salt.

From the blenders, the finished mass, at a temperature of 45-50° F., is extruded through a die, by a screw press or other means, and the extruded slab is cut up into blocks or prints and immediately wrapped and packaged. Votator-made margarine is extruded directly from the votators.

Margarine will ordinarily consist of about 80% fat, 17% milk, and 3% salt. A number of optional ingredients, in addition to milk, salt, and fat, are sometimes used in margarine in very small amounts. These include monoglycerides and other edible surface-active materials, to promote emulsification and prevent spattering when the margarine is used in frying; vitamin concentrates; preservatives; and yellow coloring materials.

The manufacture of margarine, like that of most other food products, requires observance of the fundamental principles of sanitation. In culturing and ripening the

³⁴ A. A. Robinson, *Oil & Soap*, 15, 203 (1938).

milk, care must be taken to avoid stray bacterial contamination, and during the processes of mixing, solidification, packaging, etc., the product must be protected from both bacteria and molds.

3. Superglycerination of Shortenings

Since about 1934, the use of superglycerinated or "high-ratio" shortenings,^{35, 36} for making cakes and sweet pastries and cream icings, has become widespread in the United States. These shortenings contain an excess of combined glycerol, in the form of mono- and diglycerides. The advantage of these glycerides lies in their effectiveness in promoting emulsion between fatty and aqueous ingredients in the cake dough. The high degree to which the fat may be dispersed and the consequent mechanical strength of the emulsion enable the baker to increase the liquid content of his cake doughs greatly without weakening them sufficiently to cause them to fall during the baking operation. This increase in liquid content permits the use of higher ratios of sugar to flour, and the consequent production of a sweeter cake. Thus with high-ratio shortenings, the ratio of sugar to flour may be as high as 140:100 by weight, whereas with ordinary shortenings the maximum ratio possible is about 100:100.

Mono- and diglycerides for high-ratio shortenings are prepared by reacting a fat, usually a partially hydrogenated cottonseed oil, with one-fifth to one-sixth of its own weight of glycerol. Sodium hydroxide, or other alkali, in sufficient quantity to saponify about 0.5-1.0% of the oil, is used as a catalyst for the reaction. The reaction is conducted in a closed vessel, with stirring under an atmosphere of hydrogen or other inert gas at 425-475° F. A reaction time of 0.5-3 hrs. is required. A vessel of aluminum, nickel, or stainless steel is suitable for the process; ordinary steel cannot be used, as it will contaminate the product with iron. After the reaction is completed, the batch is cooled to approximately 200° F., and strong phosphoric acid, in about 50% excess on the basis of the alkaline catalyst, and a small amount (*ca.* 0.5%) of diatomaceous earth are added. The batch is then agitated under a vacuum until thoroughly dehydrated, after which it is cooled and then filtered. The soap formed by the alkali is decomposed with the formation of insoluble sodium phosphate, which is filtered out with the diatomaceous earth. The alkali must be completely removed, as it is highly detrimental to the keeping quality of the fat.

The resulting product consists of a mixture of mono-, di-, and triglycerides, together with a small amount of free glycerol and fatty acids, and will contain about twice as much combined glycerol as the original triglycerides. In the preparation of a high-ratio shortening, about 6% of the above product is added to a batch of ordinary shortening during the deodorization of the latter and very shortly before deodorization is completed. Mono- and diglycerides are unstable under deodorization conditions, and are inclined to revert to triglycerides with the liberation and distillation of free glycerol. If their deodorization period is restricted as above, however, they will be

³⁵ H. S. Coith, A. S. Richardson, and V. M. Votaw, U. S. Patents 2,132,393 and 2,132,394 (1938).

³⁶ B. R. Harris, U. S. Patent 2,132,416 (1938).

sufficiently freed of odoriferous substances and uncombined glycerol without suffering any undue degree of decomposition.

The use of mono- and diglycerides in shortening and some of the details relating to their manufacture are patented. So far, no other surface-active materials have been found which are effective in producing high-ratio shortening.

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Chapter XXIII

NONALCOHOLIC BEVERAGES

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The almost phenomenal acceptance of nonalcoholic carbonated beverages as a form of refreshment is explained on the basis of a scientific history which begins with the experiments of the early naturalists in an era when scientific observation began to overthrow the misconceptions of alchemy, and extends to the highly perfected era of present-day food technology. The naturally carbonated waters of the world were a basis of speculation in earlier times—those who drank the enlivened waters were thought to receive some additional factor which added to the mysterious functions of the human body. Carbonated waters of nature are usually highly mineralized. The carbonation added to the palatability and the minerals undoubtedly had some physiological action which caused these waters to be sought out the world over.

Experimenting with carbon dioxide gas collected from beer vats, Joseph Priestley, in 1767, found that he could introduce the gas into water and give it a taste similar to that of naturally carbonated waters. Further steps in simulating natural waters were made by the Swedish chemist, Bergmann, in 1770, who combined mineral elements found in chosen springs and generated carbon dioxide gas from chalk and vitriol for carbonation. When the natural springs were inaccessible, patrons began to turn to artificial mineral waters which matched their favorite natural formulas.

In America, around 1785, Dr. Philip Physick of Philadelphia was treating the sick with mineral waters and went to Druggist Townsend Speakman for help in producing an artificially carbonated mineral water. Speakman did not stop when he actually made an apparatus for carbonating water for Dr. Physick, but added fruit juices to carbonated water and became what is known as the founder of the carbonated beverage industry. In a short space of time, many other flavors were combined with carbonated waters and furnished pleasant, refreshing beverages. The remarkable strides made in the bottled carbonated beverage industry soon began, and the advancements made in machinery and technological developments in the 20th century brought carbonated beverages into wide production. In 1941, there were more than 6000 carbonated beverage manufacturing establishments in the United States employing some 75,000 people and producing merchandise with an estimated value of \$500,000,000.

In the more commonly accepted classification, nonalcoholic beverages are normally thought of as soft drinks. However, soft drinks embrace both carbonated and still beverages. The carbonated beverage may be either flavored with sugar, essence, and acid, or unflavored, containing carbon dioxide and minerals. The still beverage may either be fruit juice with or without added sugar and water, or it may contain flavoring material, sugar, and acid, properly proportioned with water. The distinctive methods of manufacture and distribution of bottled carbonated beverages have made these products universally available, and consumer acceptance has been so general that bottled soft drinks might well be termed America's most widely accepted form of beverage refreshment.

The refreshing properties of these beverages undoubtedly lie within the skilled blending of highly refined ingredients to produce a constant but not too pronounced flavor. Instead of a heavy definite flavor, the ingredients are blended and complemented in such a way that they cannot be too readily defined and thus form a basis for stimulating repeat consumption. The basic raw materials and processing that go into the make-up of carbonated beverages will be described in connection with certain manufacturing details pertaining to the soft drink industry.

1. Carbon Dioxide and Carbonation

Carbon dioxide for beverages can be produced by various methods. Its evolution by the reaction of certain chemicals was the system employed in bottling plants until liquefied and solid carbon dioxide became available on a commercial scale. For the generation of carbon dioxide by chemical means, chalk, limestone, or bicarbonate of soda is acted upon by sulfuric acid. The advantage of using bicarbonate of soda is that of a greater yield of gas, for soda does not vary in composition as do chalk and limestone. Liquefied and solid carbon dioxide gas are usually by-products of some industrial process. In the brewing industry, for example, carbon dioxide is a by-product developed during the action of yeast on sugar. The combustion of coal, coke, and natural gas is another source of supply. Tube-gas and dry ice have supplanted the older method of gas generation. The relative merits of the liquid and solid carbon dioxide forms of the gas are a matter for discussion. The solid form has been more recently introduced and is making considerable progress.

Since carbon dioxide in the beverage furnishes its identifying characteristic, naturally the question arises in beverage manufacture as to the amounts of carbon dioxide gas, generally referred to as carbonation, most desirable in beverages. There is no general, all-inclusive answer to this question, for suitable carbonation depends on the type of beverage and the manner in which it is to be used. It is generally conceded that carbon dioxide gas is most important because of the pungent acidic taste it gives to the beverage, plus the beneficial physiological effects it has on the digestive system. The gas brings about a visual attraction by causing the small bubbles to come out of the liquid, a process often called "pearling" or "sparkling," adding life and interest to the beverage.

CARBON DIOXIDE AND CARBONATION

TABLE 59
GAS VOLUME TEST CHART
(Showing Volumes of Carbon Dioxide Dissolved by 1 Volume of Water)

H ₂ O bottle temp. °F.	Gage pressures in bottle, lbs. per sq. in.													
	18	20	22	24	26	28	30	32	34	36	38	40	42	44
45	2.7	2.9	3.1	3.3	3.4	3.6	3.8	4.0	4.1	4.3	4.5	4.7	4.8	5.0
46	2.7	2.8	3.0	3.2	3.4	3.5	3.7	3.9	4.0	4.2	4.4	4.6	4.7	4.9
47	2.6	2.8	2.9	3.1	3.3	3.5	3.6	3.8	4.1	4.3	4.6	4.8	5.0	5.2
48	2.6	2.7	2.9	3.1	3.2	3.4	3.6	3.7	3.9	4.1	4.2	4.4	4.5	4.7
49	2.5	2.7	2.8	3.0	3.2	3.3	3.5	3.7	3.8	4.0	4.1	4.3	4.5	4.6
50	2.5	2.6	2.8	2.9	3.1	3.3	3.4	3.6	3.7	3.9	4.0	4.2	4.4	4.5
51	2.4	2.6	2.7	2.9	3.1	3.2	3.4	3.5	3.6	3.8	3.9	4.1	4.2	4.3
52	2.4	2.5	2.7	2.8	3.0	3.2	3.3	3.5	3.6	3.8	3.9	4.1	4.2	4.4
53	2.3	2.5	2.6	2.8	2.9	3.1	3.3	3.4	3.6	3.7	3.8	4.0	4.2	4.3
54	2.3	2.4	2.6	2.7	2.9	3.0	3.2	3.3	3.5	3.6	3.8	3.9	4.1	4.2
55	2.3	2.4	2.6	2.7	2.8	3.0	3.1	3.3	3.4	3.6	3.7	3.9	4.0	4.1
56	2.2	2.4	2.5	2.6	2.7	2.8	2.9	3.1	3.2	3.4	3.5	3.7	3.8	3.9
57	2.2	2.3	2.5	2.6	2.7	2.9	3.0	3.2	3.3	3.5	3.6	3.7	3.9	4.0
58	2.1	2.3	2.4	2.6	2.7	2.8	3.0	3.1	3.3	3.4	3.5	3.7	3.8	3.9
59	2.1	2.2	2.4	2.5	2.7	2.8	2.9	3.1	3.2	3.3	3.5	3.6	3.7	3.9
60	2.1	2.2	2.3	2.5	2.6	2.7	2.9	3.0	3.1	3.3	3.4	3.5	3.7	3.8
61	2.0	2.2	2.3	2.4	2.6	2.7	2.8	3.0	3.1	3.2	3.3	3.5	3.6	3.7
62	2.0	2.1	2.3	2.4	2.5	2.6	2.8	2.9	3.0	3.2	3.3	3.4	3.6	3.7
63	2.0	2.1	2.2	2.4	2.5	2.6	2.7	2.9	3.0	3.2	3.4	3.5	3.6	3.8
64	1.9	2.1	2.2	2.3	2.4	2.6	2.7	2.8	2.9	3.1	3.2	3.3	3.5	3.6
65	1.9	2.0	2.2	2.3	2.4	2.5	2.6	2.8	2.9	3.0	3.1	3.3	3.4	3.5
66	1.9	2.0	2.1	2.2	2.4	2.5	2.6	2.7	2.8	3.0	3.1	3.2	3.3	3.4
67	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.6	2.7	2.8	2.9	3.0	3.2	3.3
68	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1
69	1.8	1.9	2.0	2.1	2.2	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.2	3.3
70	1.7	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.7	2.8	2.9	3.0	3.1	3.2
71	1.7	1.8	1.9	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1
72	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0
73	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0
74	1.6	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0
75	1.6	1.7	1.8	1.9	2.0	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0
76	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.4	2.5	2.6	2.7	2.8	2.9	3.0
77	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	3.0
78	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8
79	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8

^a Figures in this column represent the volume of carbon dioxide gas (reduced to 0° and 760 mm.) dissolved by 1 volume of water at the temperatures indicated, if the partial pressure of the carbon dioxide gas is 760 mm. Hg. Solubility data correspond to Boehr and Bock published in Landolt-Bornstein, *Physikalisch-Chemische Tabellen*. Figures in the body of the table were calculated for various temperatures and pressures based on the Boyle-Mariotte law for isothermal compression.

To understand why the gas comes out of the beverage as the pressure is released by removing the crown requires a consideration of the actual process of carbonation. When the pressure of the carbon dioxide gas is only that of the atmosphere, the gas dissolves in amounts determined by the temperature of the water. To obtain greater amounts of carbon dioxide in solution, it is necessary to increase the pressure of the gas on the water, this increase causing a proportionate increase in the amount of gas dissolved. In accordance with physical laws, gas can be compressed into smaller volumes by increase of pressure, the product of pressure and volume remaining constant with slight modification due to the partial combination of gas and water. The amount of gas contained in a liquid is expressed as "volumes" in the beverage industry, which means that the amount of gas dissolved or disappearing in the liquid, if removed, would be that number of volumes of the water out of which it came. To obtain the necessary amounts of carbon dioxide in solution for beverage purposes, a mechanical device known as the carbonator agitates refrigerated water under controlled gas pressure. Uniformity in the temperature of the water and gas pressure is essential to satisfactory carbonation.

The extent of carbonation is therefore measured by temperature and pressure. The accompanying gas volume chart (Table 59) shows the volumes of carbon dioxide dissolved in one volume of water with respect to temperature.

2. Sugar and Sirup Making

Much of the flavor character and food value of nonalcoholic beverages depends upon the types and amounts of sugar in the product. Sucrose, either of cane or beet origin, is the most widely used sweetening agent. However, dextrose, processed from one of the starchy cereals such as corn, has been found highly suitable for beverage manufacture. It is used principally in conjunction with sucrose. Levulose, lactose, maltose, and other sugars have not found a place for economical reasons as commercial sweetening agents.

Commercial sirups, either cane, beet, or corn, are products of shortened manufacturing processes which eliminate such steps as boiling to the crystallization point, centrifuging, washing, and drying necessary for the production of crystalline sugars. Because the crystallization process, which is an important purifying medium, has been eliminated, such sirups carry certain impurities which may act as growth-promoting substances; and unless scrupulous care is exercised in the manufacturing process, a serious spoilage hazard may be involved. When facilities in the manufacturing process and the type of product permit, commercial sirups are used as sweetening agents.

High bacteriological standards for sugars and sirups and scrupulous sanitation are emphasized in beverage manufacture because the keeping properties of the finished products are predicated upon all ingredients being free of spoilage-type microorganisms. This is particularly important because the final package is not heat-treated.

The preparation of sirups is one of the most important operations in the beverage plant both from the standpoint of sanitation and control of concentration. Sugar dissolved in water is customarily referred to as simple sirup; the proportions of sugar and water are selected in order that the final solution will be of the required strength. Simple sirups prepared in the beverage plant usually range from 55 to 65% sugar by weight, depending, of course, upon the individual formula. When acid is added to the sirup, it is known as acidified simple sirup. When the sirup has been completely prepared by addition and blending of all flavoring ingredients, it is known as flavored sirup. As the final manufacturing process, flavored sirup is blended with carbonated water, either immediately before the bottles are filled or actually in the bottles during the filling operation. Sirup may be prepared by what is known as the *cold process*, which comprises the mixing of sugar with water at or about room temperature. This may be carried out directly without the addition of acid or may involve the use of acid to obtain a preserving effect against microorganisms. This method of sirup manufacture is satisfactory only under the most carefully controlled sanitary conditions. In the *hot process*, sirups are heated to facilitate dissolving the sugar and to bring about destruction of the microorganisms.

When sirups are to be stored for several days, the hot process (pasteurization) has proved beneficial. When sirup is stored beyond a few hours or overnight, it has been shown that high-density sirups in the range above 36° Bé. have a definite retarding action on the growth of microorganisms. This action can be materially increased by the addition of approximately 1.0% citric, phosphoric, or lactic acid to the high-density sirup. Sirups lighter than 30-32° Bé. should not be stored at all, as yeast will grow rapidly in such solutions.

Thus, two methods are generally used for controlling microbial growth in sirups: (1) hot process or pasteurization; and (2) use of high-density sirup or high-density sirup plus acid. Both methods are considered equally effective. The success of the latter depends upon very rigid sanitary precautions because high-density sirups and acidified sirups are media naturally inhibitory to microbial growth.

Pasteurization, the heating process designed to kill or reduce the number of objectionable organisms, is usually effective at either of two combinations of temperature and holding time, namely: 32° Bé. sirup boiled for 5 min. and cooled; 32° Bé. sirup with approximately 1.0% acid heated to 180° F. and then cooled. Pasteurization does not guarantee the sirup will be free from contamination after processing. Adequate sanitary storage and handling facilities are required through subsequent operations.

The keeping properties of any sirup and resulting beverage are predicated upon a low incidence of microorganisms.

3. Acids and Acidulation

The characteristic flavor of beverages is developed in part through proper acidulation which points up or complements the associated flavor. The commonly employed acids are citric, phosphoric, and tartaric, with lesser amounts of lactic and malic acids

used. Citric acid is the acid of citrus fruits. Phosphoric acid is present in the form of phosphates in many foods. Tartaric acid is the acid characteristic of grapes. Lactic acid is associated with sour milk and dairy products. Malic acid is the acid occurring in apples. Each of these acids is usually associated with the product from which it comes. Citric acid is the most widely employed because it adapts itself well to nearly all light or fruity flavors. Phosphoric acid has found wide use in the more heavy leaf, root, nut, or herbal flavors. Tartaric acid is used in grape flavors.

The kind of acid and the concentration employed are therefore very significant considerations in adjusting the flavor of the beverage. The actual quantity of acid does not tell the whole story in regard to taste. The intensity of the acid (expressed by hydrogen-ion concentration) gives a more complete picture. Certain flavors and water conditions are known to have various effects upon the hydrogen-ion concentration to the extent that special adjustment is required for each specialty flavor and individual differences in water conditions. The alkalinity of bottling water is adjusted by chemical treatment in order that beverages in various localities may have the same reaction and be of uniform taste. Small quantities of alkali carried over in improperly rinsed bottles are significant enough in certain cases to affect the intensity of the acid. It can, therefore, be appreciated that beverage acids play a very delicate role in the flavor structure of the beverages.

The quantity of acid to be used is determined by neutralization of a standard solution of alkali in the presence of the appropriate indicator or electrical instrument designed to show the completion of the reaction. This measurement of acid is expressed as normality, percentage, or grains per gallon. The latter is the more common designation used in the beverage industry. The intensity of the acid is the actual hydrogen-ion concentration measured by either chemical indicators or electrical instruments. This property of an acid as it affects both measuring instruments and taste can be altered by materials known as buffers. Substances such as flavors and other normal ingredients may have this effect.

Fifty per cent citric acid is widely used as a stock solution in the industry. Therefore, such questions as how to use 85% and various other percentages of phosphoric and lactic acid to get the same results as the citric stock are significant problems. Some types of flavors seem to tolerate the change of acids better than others. However, in certain cases it may be found more advantageous to blend two or more of these acids to produce the desired acidity. Inasmuch as the use of alternate acids is not a simple substitution, experimental runs should be made, combined with tasting checks or checking by a laboratory along with observations for sedimentation or color change.

There are a number of beverage acidifiers on the market appearing under trade names which are blends of two or more of the recognized acids adjusted to approach the properties of a 50% citric solution. Because the bottler is responsible for the ingredients in his beverages, the properties and ingredients of such specialty compounds are supplied by the manufacturer.

All acids used for beverages must be "edible grade."

4. Water and Water Treatment

The carbonated-beverage industry is vitally interested in the characteristics of water, as water constitutes such a large proportion of the finished product. To be considered suitable for beverage purposes, a water must be of unimpeachable sanitary quality; it must be free of suspended matter and coloring materials; it must be clear, and not contain excessive mineral or other substances which may affect the flavor or give rise to objectionable tastes and unsightly deposits in the finished product; and it should preferably be of low alkalinity. The water-treatment problem, therefore, consists of methods for controlling the physical characteristic, mineral components, and sanitary qualities.

The physical characteristics as influenced by suspended matters, color, odor, and taste are usually controlled by a combination of chemical and mechanical methods. *Coagulation* and *filtration* are such processes. They are generally employed in conjunction with *chlorination*, designed to remove excessive alkalinity, color, hardness, taste, and odor in a unit operation.

Chemicals such as alum, sodium aluminate, and ferrous sulfate have the property of forming flake-like particles. When mixed with water and allowed to settle mechanically, these particles enmesh the suspended materials and remove them from solution. Incorporated with the coagulation-settling process for simultaneous action are usually lime and chlorine. The lime removes temporary hardness and alkalinity by changing soluble calcium bicarbonate to insoluble calcium carbonate, which is in turn precipitated along with the floc produced by the coagulating chemical. Chlorine is effectively employed for destroying color in the water if the pigment is of the soluble or colloidal type.

Ozonation is employed as a separate operation to the coagulation and lime treatment. The use of either chlorination or ozonation processes is a matter of choice. These types of treatment also assure bacteriological sterility of the water.

The water from the coagulation treatment unit is usually passed under pressure, through sand filters and activated carbon units, for the removal of suspended matter, excess chlorine, residual tastes, and odors. Paper or fibrous sheet filters are sometimes installed for light duty or so-called polishing the water. These are in most cases used after sand filtration and activated carbon treatment. Filtration is a mechanical method for removing suspended matters from water. The sand unit is an adaptation of the slow sand filter (gravity principle) used in municipal water treatments. Efficient operation of the pressure filters depends upon controlled operation in regard to rate and constancy of flow, frequency of backwash, and sterilization procedures. Paper and fiber sheets are supported in a frame to allow passage of the water. The correct fiber porosity and rate of flow are important control factors.

For certain types of odors due to microorganisms and mineral components in water, one or a combination of the following processes may be employed: aeration is used to remove as much as possible of the volatile odoriferous substances. Ozonation or chlorination is an oxidization process which destroys objectionable organic

odor and taste matters. Activated carbon and deaeration are treatments which remove undesirable tastes and odors imparted to the water by oxidation processes employed.

Organic materials with ion-exchange properties have recently been developed, and offer a unique process for removing alkalinity by introducing sodium and removing calcium and associated alkalinity from the water. In the process, hydrogen ions are given up to the water. In an additional resin contact bed which has the property of giving up hydroxyl ions and taking up such substances as chlorides, sulfates, and carbonates, principally, all the salts can be removed from aqueous solutions to produce a product comparable in quality to distilled water. The cation system is regenerated with acid and the anion, with either salt or alkaline materials.

Zeolite, an inorganic base-exchange substance, is a process of mineral base-exchange effective for removal of permanent hardness, but is not effective for removal of alkalinity and the total amount of dissolved matter in the water is not appreciably changed. The lime process is effective in removing temporary hardness and its associated alkalinity. For this reason the lime process is more generally used in the treatment of water for beverage manufacture and the zeolite is more successfully employed for treatment of water in connection with bottle washing.

Distillation will, of course, remove all the nonvolatile and insoluble components, but such refinements are not generally demanded by the beverage industry. A more detailed treatment of water for industrial purposes is given on pages 804 *et seq.*

The sanitary quality of water employed in beverages should at all times meet the bacteriological standard established for interstate common carriers by the United States Treasury Department. Not only is it required that water be absolutely free from any evidence of disease-producing bacteria, but freedom from spoilage type organisms is necessary. In the bottling plant heat, light, and chemicals are methods employed for water sterilization.

5. Coloring Agents and Coloring

The colors used in making beverages are generally prepared by manufacturers specializing in this field. The products are adapted for specialized use in regard to stability and concentration necessary for the beverage industry. The use of coloring agents is confined to the permissible or certified type, indicating that they are entirely suitable for use in food products. See Volume I, page 303. Coloring agents used in bottled carbonated beverages are, almost exclusively, certified coal-tar colors and caramel, although color in some cases is derived from the flavoring substances used. Coloring agents for successful use should, of course, have standard coloring power, stability, and no interfering taste and odor, and should be free from both biological and chemical contaminants.

Caramel is made by processing sugar or starch. The use of caramel in beverages gives its characteristic dark to light brown color and is usually associated with flavors of the type derived from root, leaves, herbs, and berries. Coal-tar colors are certified for use in food products by the Federal Government.

The methods of preparing solutions from dry coloring bases and dilution of concentrate coloring materials require accuracy in measurements and scrupulous sanitary precautions against microbial contamination. Aqueous solutions of these materials support the growth of spoilage organisms. Additions of alcohol, citric acid, and sodium benzoate to the dye solutions, as well as boiling and steam pressure sterilization, are measures used to control biological growth.

6. Flavoring Materials—Flavoring

Flavoring materials used in making carbonated beverages are primarily alcoholic extracts, aqueous solutions, and fruit concentrates. Alcoholic extracts are used for many of the oily types of ingredients which require alcoholic extraction from the source material and cannot be carried in similar volumes of water. Aqueous solutions are used for water-soluble ingredients and the preparation of emulsions. Fruit concentrates furnish a greater flavoring strength than is found with the natural juices and, when reconstituted into beverage strength, bring out the natural flavor. The inherent concentrated property of flavoring materials and specialized methods of handling and storing afford natural protection against unfavorable changes attributed to microorganisms, air, and separation, provided reasonable care is exercised.

TABLE 60
COMPOSITION OF CARBONATED BEVERAGES

Flavor of beverage	Number of samples ^a	Per cent sugar ($^{\circ}$ Brix)	Gas, volumes	Grains of citric acid per gal. ^b
Kola flavors	20	10.5	3.4	51
Cream (vanilla)	15	11.2	2.6	9
Ginger ales				
Golden	38	10.2	3.5	61
Pale Dry	42	8.8	3.8	72
Grape	12	13.2	2.2	56
Lemon and lime	18	10.8	3.4	95
Lime (lithia)	10	9.6	3.7	87
Orange	30	13.0	2.1	105
Root beer	25	9.9	3.3	15

^a Representing different products and manufacturers.

^b One grain per gallon equals 0.0171 g. per liter.

Extracts containing at least 20% alcohol will remain sterile because of the preserving action of the alcohol. Certain aqueous solutions and concentrates are preserved by natural acids; and in certain cases this effect is amplified by benzoate of soda. Pasteurization as a means of protecting flavoring materials against the action of microorganisms is rather limited because of the destructive action of heat against flavors.

The materials from which essences are made vary, but the essences themselves are generally classified as being derived from materials of natural origin, compound essences, and synthetic essences. A compound essence is one which is based on a natural material and may be fortified by the addition of synthetics. Synthetic

essences are produced by various chemical reactions. In the earlier years of the bottling industry, the preparation of these materials was an integral part of each plant's operation. However, since a considerable amount of knowledge, skill, and experience is required in the compounding of essences, it is now considered a specialized industry associated with the beverage industry.

7. Container and Closure

The specialized nature of the container and closure for packaging carbonated beverages is required because of the carbon dioxide pressure in the product, the economy of glass, and the facility with which the closure can be applied and removed.

The versatility of glass has enabled many distinctive and privately designed packages to be created for specialty products. Color may be applied permanently to the glass for specialty decorations and labeling.

The variety of closures used for sealing bottles throughout the history of the carbonated beverage industry has been completely replaced by the familiar crown closure. The apparent simplicity and common usage of the crown should not be accepted without realizing that it is a product of exhaustive research and present-day manufacturing efficiency. Metal for manufacturing crowns should be of uniform ductility and gage, of even temper, and resistant to corrosive attack, both from the beverage and outside influences. The precision required of the crown demands manufacturers' uniformity. Composition cork has replaced the natural product for crown inserts. The ground cork, mixed with suitable binders, makes a more uniform product. The fact that cork can be compressed without permanent distortion and flowing is a characteristic which makes it a highly effective pressure seal.

For a certain type of product requiring special sealing conditions, spots of impervious material of a paperlike nature are affixed to the cork insert.

Recent research has shown that because of the versatility of plastic materials, there is a possibility that closures of such materials may be developed.

8. Bottle Washing and Filling

The preparation of a glass container for re-use is one of the important operations associated with the manufacture of bottled carbonated beverages. Almost completely automatic machinery for *bottle-washing* plus the use of specialty chemical bottle washing compounds have added much to the efficiency of this process. Various mechanical principles are employed in applying the detergent solution to the bottle. Some washers are of the soaking type, others make use of the hydro principle, and some use combinations of both. Mechanical adaptability of the machine is based upon the particular washing problem involved in regard to volume of production and size of bottles.

Automatic machinery takes the clean bottle from the washer and passes it through simultaneous operations of filling, crowning, mixing, and labeling. *Filling* is usually carried out in two operations, the flavored sirup being added before the carbonated

water; there are variations in the mechanical methods by which these operations are handled. One method of filling operation, a comparatively recent innovation, premixes the carbonated water and flavored sirup, thereby reducing the filling operation to a single step. Filling is a mechanical operation which requires considerable precision. Some of the larger machines fill over 200 six-oz. bottles per minute with a narrow tolerance for variation in measurements, often not exceeding one part in 100.

The criterion for satisfactory re-used bottles is that they be sterile, rinsed free of the chemical sterilizing agent, of acceptable appearance, and of good mechanical strength. In order to achieve these standards, certain factors must be controlled in the bottle-washing operation. They are as follows:

1. Concentration of sterilizing and detergent agent.
2. Composition of the agent.
3. Temperature of washing solution.
4. Time of exposure of bottle to the agent.
5. Condition of rinse water.
6. Mechanical suitability of machinery to bottles.

Investigations sponsored by the American Bottlers of Carbonated Beverages on bottle-washing compounds have shown that, to sterilize bottles properly under recommended conditions by recognized mechanical methods, washing solutions should comply with the following, or its equivalent: a 3% alkaline solution, of which not less than 60% is caustic soda (1.8% sodium hydroxide), with immersion time of 5 min. and temperature of 130° F. Temperatures of washing solutions are controlled automatically and records are kept by means of continuous recording instruments. The time of exposure is governed by the capacity of the machine and mechanical adjustments.

The concentration and composition of the alkaline washing solutions are determined by the American Bottlers of Carbonated Beverages' alkali and caustic tablet titration methods, or by titration with standard acid solutions and in some cases by electrical methods. The agent used in the alkali test tablet is an acid substance, carefully prepared and compounded into tablets of definite composition.¹ An indicator is combined with the acid substance for the purpose of showing when the reaction between the acid substance of the tablet and the caustic of the washing-solution sample has been completed. The amount of this mixture used in each tablet is such that, if 10 ml. of washing solution is used, each tablet will represent 1% alkali as caustic. This is the total alkali strength including caustic and milder alkalies. The indicator of the tablet gives a sharp color change from blue in the presence of an alkali to yellow in the presence of an acid.

¹ A. B. C. B. Alkali Test Tablets (U. S. Patent 1,721,809) contain bromphenol blue indicator, potassium acid sulfate, and inert binder. A. B. C. B. Caustic Test Tablets No. 1 (U. S. Patents 1,721,809, 1,912,473) contain tropaeolin O indicator, barium chloride, and inert binder. A. B. C. B. Caustic Test Tablets No. 2 (U. S. Patents 1,721,809, 1,912,473) contain potassium acid sulfate and inert binder.

Investigations have shown that total alkalinity is not the most important factor to be considered in the composition of washing solutions. It has been proved that caustic alkalinity is very important as a sterilizing agent. The caustic tablet titration process is a two-step procedure differentiating between caustic and total alkalinity. However, the same procedure and equipment are used as in the alkali test. The preliminary tablet is used to add the indicator and remove noncaustic alkalinity from the solution by chemical means for subsequent test with the acid-titration pill.

The accuracy and applicability of these methods have resulted in their wide use by all industries preparing bottles for re-use and by health authorities as control test methods. The use of standard acid solutions and indicators for determining the strength and composition of bottle-washing solutions is limited because of the special skill required to apply the method. Electrical devices are used in some of the larger operations.

After the bottles have been cleaned and sterilized, a series of fresh-water rinsing operations is required to remove the alkaline material from the bottle. It is important that water for this purpose be potable and of such chemical nature as not to produce cloudy bottles and cause scaling in the rinsing equipment of the machine.

9. Agents Causing Spoilage

Spoilage in most food products may be looked upon as any change from a desired condition or standard of the material. Since these changes are usually the result of physical, chemical, or biological action, the control of spoilage in a general way may be looked upon as blocking, through controlled methods, a series of natural occurrences and changes which may otherwise occur in the product. The general effects are summarized without attempting to draw too definite bounds (see Volume I, page 356). Light and temperature are physical agents. Some chemical agents are inherent in foods, or may be added at any time during processing. Oxygen of the air is a particularly familiar chemical agent. Enzymes and various microorganisms are classified as biological agents. Their action is manifested by some change in the appearance, color, flavor, odor, or texture of the product, or in the formation of turbidity, sediment, etc. These various factors often act together, and it is often difficult to isolate their specific effects. Such actions can be considered individually as they apply to carbonated beverages.

(a) Physical

The effect of sunlight upon beverages is, no doubt, known to everyone who has been in the business of manufacturing a general variety of beverages for any length of time. The beverages containing a true fruit base are often much more sensitive to light than other types; however, all beverages are sensitive to some extent. Exposure to direct sunlight produces very undesirable flavor changes, the taste often being described as oily, terpene-like, or sour, or by a general loss of flavor. Every precaution should be taken to keep beverages from the direct rays of the sun during storage in the plant, at the sales outlet, and on the truck.

Abnormally high or low temperature ranges also have a harmful effect. Freezing usually causes a change, for when the product is brought to serving temperature (approximately 40° F.) after being frozen, precipitation and a change of color sometimes take place. High temperatures (over 100° F.) may cause the same effect and also alter the flavor.

(b) *Chemical*

Among the chemical compounds which are likely to spoil a beverage are those associated with the flavoring materials. Some of these undergo changes which result in undesirable tastes or loss of flavor entirely. Similarly, sugars such as sucrose change by a process of inversion to simple sugars, which may have a different character of sweetness. With these substances, heat and light, as well as enzymes occasionally, may act to speed up the changes. It is also known that the acidity or alkalinity (pH) of the product has an effect, usually on the rate at which changes occur.

In general, spoilage results from foreign chemical substances in the water and flavor ingredients, or on the bottles and crowns. Excessive alkalinity of water, as well as high mineral contents, often results in irregularity or alteration of beverages produced. Many times the water carries obvious amounts of chlorine from municipal water works or because of other treatment; highly flavored chemical substances produced in small amounts by biological growths; or materials with which the water has come into contact. Occasionally, water carries, in addition to biological growths, suspended matter which settles out as a sediment on bottling.

Air is a chemical, introduced into the product as a foreign gas, usually unintentionally. However, it contains oxygen which will alter many flavoring materials and aid in the changes brought about by other causes, such as light, heat, enzymes, or some of the other chemical substances in the product. Oxygen is also considered an aid in the development of many types of microorganisms.

(c) *Biological*

Enzymes, which are naturally occurring substances present in all living matter, function in metabolic processes. After plant or animal substances are taken from their original state and partly processed for food usage, these enzymes often continue to act, causing undesirable changes in the product. Their continued activity results, for example, in oily, rancid, or what is called a "terpene" taste in many fruit-type flavors. Such activities may be materially controlled by storage at low temperature, elimination of contact with air, and storage away from bright, direct sunlight.

Microorganisms are usually referred to as those forms of plant and animal life too small to be seen individually with the naked eye. However, by virtue of their growth habits, they manifest their presence in such form as scums, colonies, clouds, sediments, etc. There are generally five groups of such microorganisms discussed in

connection with food preservation, namely, protozoa, algae, molds, bacteria, and yeast.

Protozoa are one-cell animals, using as their food organic matter such as decomposed animal and vegetable waste, and living animals and plants. Their occurrence in water or other raw material used in food processing is not desirable, since large numbers of such organisms often have a characteristic taste which may be carried into the final product. For this and other reasons, they are not desirable in food products.

Algae are small microscopic plants bearing a green pigment, chlorophyll, or pigments similar in function. Through the medium of their green pigment, plus sunlight, carbon, hydrogen, and oxygen, these forms are able to build their own complex bodies. Their mass growths are familiar in the green scum or cast which open bodies of water have at certain seasons of the year. These organisms impart the odor which is so characteristic of bodies of water. Here again, if a sufficient number of these organisms are carried into a beverage, an undesirable taste and odor result. The very nature of the growth habits of these organisms indicates that their source is water which has been exposed to light. Since the conditions along the processing route are not suitable for their multiplication, the numbers present indicate the range of numbers introduced from the natural source open to the atmosphere. Algae and protozoa are effectively removed from water by carefully operated clarification, sedimentation, or filtration methods. Where they are not removed, they may cause sediments and flavor change in finished beverages.

Molds are filamentous forms often looking like cotton when growing in masses or colonies. Individually, the cells are microscopic in size and filamentous in character. Their mass growths are often observed on bread and fruits. These organisms use as food other plants and animals, that is, they are dependent ultimately upon chlorophyll-bearing plants as their source of nutriments. They have the property of requiring air (oxygen) for their growth on moist surfaces, and prefer an acid medium for optimum multiplication. A beverage properly carbonated does not normally have enough air to support their growth. However, tolerance of molds to acid makes them of concern, for they will grow in or on the surface of citric acid solutions, stored sirups, crowns, etc. When introduced into a beverage in sufficient number from these sources, they impart a musty or otherwise described off-taste.

Bacteria are small plants, microscopic in size, which are spherical in shape, or small straight or twisted rods. The effect of their growth is usually noticeable in off-color, taste, or odor. Bacteria grow in a great variety of products and under almost all conditions. A general limiting factor to their growth is acidity. The types growing in acid materials are relatively few. *Escherichia coli* is a typical intestinal-type organism. Its presence in water and foods is universally regarded as an indication of sewage pollution. The organism itself does not possess any marked pathogenic characters, but its association with such pollution indicates the probable presence of disease-producing bacteria such as the typhoid bacillus. That carbonated beverages have been found in sanitary surveys to have a low colon index is not surprising, because the combined action of the carbon dioxide and acid exerts a pronounced germicidal effect. Figure 153 shows the influence of the principal ingredients of carbonated

beverages on *E. coli* under experimental conditions. It is particularly significant that, in a solution of 3.5 volumes of carbon dioxide, 0.085% citric acid, and 10% sugar (a condition simulating bottled carbonated beverages), over 4,500,000 cells per ml. were completely killed in less than 36 hrs. The same trend is indicated in the absence of carbon dioxide from the above solution; but it seems that the combined effect of carbon dioxide and acid is more positive. Since the typical acidified carbonated beverage does not readily support the growth of bacteria, they are of limited concern in this industry. However, they cannot be totally dismissed, for there are some types of products in which they will grow.

Yeasts are microscopic organisms, slightly larger than bacteria, and have as their scientific name *Saccharomyces*, meaning "sugar plants." They grow more vigorously than the other microorganisms in sirups, acids, flavors, and under the general conditions accompanying the manufacture of carbonated beverages. It is therefore important for manufacturers of carbonated beverages to know in detail their occurrence, growth, and factors controlling their growth. Yeast growth is considered responsible for more than 90% of the biological spoilage in bottled carbonated beverages. Yeasts gain entrance into the beverage-manufacturing process by way of: (1) ingredient containers such as sugar sacks; (2) infection in flavors and colors; (3) dust picked up during processing; (4) general insanitary plant operation; or (5) incompletely sterilized bottles, or dusty crowns. In order to realize something of their growth characteristics, the following data are presented of their growth rates in materials associated with the manufacture of bottled carbonated beverages. In the beverage are four components which will influence the growth or death of these organisms when present, namely: acid, sugar, carbon dioxide, and possibly effects from the plain water. Some of the flavoring ingredients may also introduce extraneous growth factors. The particular strain of yeast used in these studies was isolated from spoiled ginger ale and simple sirup.

Table 61 gives an idea of the rate of yeast growth in different sugar concentrations. The growth of yeast in the weak sugar solution (1% sucrose) is very rapid. In 48 hrs., the initial number more than doubles, while in an additional 2 days the number becomes a staggering 2,000,000. In a 5% sucrose solution, the cells grow faster than in a 1% solution. These solutions are low for sugar content of a typical beverage, but are in the order of dilution of sugar left in a siruper or in the lines, and emphasize

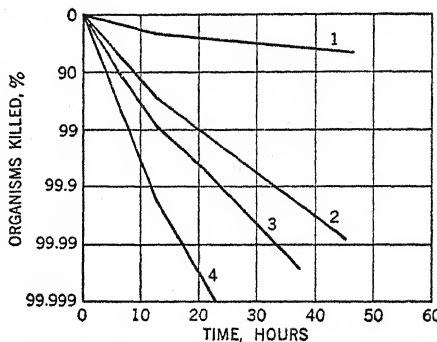


Fig. 153.—Graphic representation of the influence of the principal ingredients of carbonated beverages on *E. coli*. (1) Tap water. (2) Tap water, 0.085% citric acid. (3) Tap water, 0.085% citric acid, 10% sucrose. (4) Tap water, 0.085% citric acid, 10% sucrose, 3.5 volumes carbon dioxide. Inoculum, 4,500,000 *E. coli*. per ml. (Unpublished data courtesy W. A. Nolte, University of Maryland.)

the dangers from yeast contamination in store for those neglecting to clean the lines, filters, and filling machines. These growth rates of yeast in weak sugar solutions point out what usually happens when vessels and lines are not thoroughly flushed free of sugar and are allowed to go unused for any length of time. A 27° Bé. sirup (49.5%)

TABLE 61
RATES OF YEAST GROWTH IN SUGAR SOLUTIONS
Incubated at 28° C.—solutions made in tap water

Incubation time, hrs.	Yeast per ml. in			
	1% sucrose	5% sucrose	27° Bé. sirup (49.5%)	32° Bé. sirup (59.1%)
Initial infection	127,000	120,000	190,000	205,000
8	143,000	195,000	261,000	782,000
30	192,000	580,000	941,000	1,680,000
48	290,000	940,000	3,600,000	2,150,000
60	385,000	2,110,000	7,410,000	2,895,000
85	870,000	11,700,000	8,600,000	3,752,000
119	1,600,000	26,500,000	9,100,000	4,492,000
145	2,300,000	43,800,000	9,900,000	6,681,000
162	2,650,000	57,300,000	12,600,000	7,389,000

TABLE 62
RATES OF YEAST GROWTH IN SUCROSE-CITRIC ACID SOLUTIONS
Incubated at 28° C.—solutions made in tap water

Incubation time, hrs.	Yeast per ml. in						
	10 grains citric acid/gal.	1% sucrose, 10 grains citric acid/gal.	5% sucrose, 10 grains citric acid/gal.	5% sucrose, 50 grains citric acid/gal.	5% sucrose, 200 grains citric acid/gal.	10% sucrose, 10 grains citric acid/gal.	10% sucrose, 50 grains citric acid/gal.
Initial infection	139,000	119,000	135,000	150,000	140,000	119,000	140,000
8	129,000	121,000	...	...	...	...	...
30	93,000	133,000	169,000	47,000	6,100	159,000	...
45	4,000	140,000	195,000	...	...	...	...
60	200	162,000	220,000	...	...	...	...
85	0	197,000	233,000	11,200	...	...	...
119	....	257,000	251,000	...	...	240,000	...
145	....	770,000	292,000	400	320	...	200
162	....	1,200,000	305,000	50	...	...	...
180	....	2,700,000	310,000	...	...	2,120,000	...
220	....	2,509,000	295,000	...	15	...	...
260	....	2,000,000	290,000	...	...	1,900,000	...

NOTE: 10 grains per gallon of citric acid in 0.017% acid.

50 grains per gallon of citric acid in 0.085% acid.

200 grains per gallon of citric acid in 0.340% acid.

1 grain per gallon equals 0.0171 g. per liter.

sucrose) is, as stated previously, a light simple sirup. As shown in Table 61, yeast develop rapidly in it. The very fact of this rapid yeast growth in this sugar concentration is one of the reasons for using heavier sirups. A 27° Bé. sirup having an initial infection of 190,000 yeast per ml. becomes a teeming mass of yeast in 48 hrs., contain-

ing 3,600,000 per ml. In the 32° Bé. sirup (59.1% sucrose), the yeast growth is more restricted than in the 27° Bé. From the data in Table 61 the evidence for making sirups and using them as needed is evident. Prolonged storing of sirup leads to almost certain trouble. If it becomes necessary to hold sirups, they should be made up in concentrations approaching 36° Bé. for the yeast grow slowly at higher concentration. A number of studies and observations point to the fact that additional preserving action may be gained by adding the required acid to the simple sirup before storing in the amounts necessary for any flavored sirup made later.

TABLE 63
RATES OF YEAST GROWTH IN CARBON DIOXIDE-CITRIC ACID-SUCROSE SOLUTIONS
Incubated at 28° C.—solutions made up in tap water

Incubation time, hrs.	Yeast per ml. in			
	1% sucrose, 3.5 vols. CO ₂	5% sucrose, 3.5 vols. CO ₂	10 grains citric acid/gal., 3.5 vols. CO ₂	10 grains citric acid/gal., 10% sucrose, 3.5 vols. CO ₂
Initial infection	135,000	131,000	142,000	121,000
8	139,000	162,000	125,000	.....
30	142,000	510,000	79,000	.....
45	161,000	.....	7,000	139,000
60	187,000	.....	500	.....
85	263,000	9,600,000	10	.....
119	730,000	23,000,000	.....	195,000
145	1,240,000	47,000,000	0	.....
162	1,710,000	58,000,000	.....	.....
180	2,100,000	75,000,000	.....	340,000
220	1,900,000	93,000,000	.....	.....
260	1,800,000	94,000,000	.....	430,000

Table 62 shows the growth of yeast in sucrose-citric acid solutions. Yeast transplanted in 10 grains per gallon (0.017% citric acid) die off very rapidly; however, the addition of 1% sucrose to this concentration of acid encourages the growth to a very high number. It is interesting to note that $\frac{2}{3}$ g. (10 grains) of citric acid added to 5% sucrose slows down the rate of yeast growth compared with the sugar alone in Table 61. Then if the concentration of acid is increased to 3.2 g. (50 grains) per gallon in 5% sucrose the yeast die off rather rapidly; this is more markedly true in solutions containing 12.9 g. (200 grains) citric acid in 5% sucrose. The yeast grow to a limited extent in the presence of $\frac{2}{3}$ g. (10 grains) of acid and 10% sucrose. These data give a very clear insight into the reasons why so much spoilage is found in low-acid and low or noncarbonated beverages.

In Table 63, another viewpoint of yeast growth is seen in carbonated-sucrose-citric acid solutions. The general effect is that carbon dioxide seems to exert some retarding effect upon the rate of yeast growth. This is particularly noticeable in solutions containing 3.5 volumes carbon dioxide, 10% sucrose, and $\frac{2}{3}$ g. (10 grains) of citric acid per gallon.

10. Manufacturing Control

Control of uniformity of the finished beverage has been greatly facilitated by standardization of basic ingredients and the use of control test check methods in the plants, and through the services of many control laboratories throughout the industry. It is the policy of most companies to require bottlers operating under their franchise to submit frequent samples to their laboratories for checks on quality control. This has led to the recognized fact that specialty items have a uniform taste appeal the country over.

It is necessary to make both chemical and biological quality control tests on all raw materials, manufacturing operations, and the finished product.

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Chapter XXIV

ALCOHOLIC BEVERAGES

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I. MALT BEVERAGES

Beer or a very similar product originated in ancient times. The histories of the early Egyptians, Greeks, Romans, and very early English tribes all have some reference to brewing. It seems that practically every civilized or semicivilized country had its own particular form of beer. A general survey would indicate that the use of malt liquor seems to be more uniformly and widely distributed throughout the world than that of any other class of alcoholic beverage.

In the United States the consumption of malt beverages is steadily increasing. Production from July 1, 1940, to January 31, 1941, amounted to 29,910,995 bbl. (31 gal. each). From July 1, 1941, to January 31, 1942, it was 35,889,099 bbl. About 8,000,000 bbl. are normally in stock. Of approximately 530 breweries operating in 1942, Wisconsin had 73; Pennsylvania, 72; New York, 49; Illinois, 44; Ohio, 44; Michigan, 31. The largest amount, more than 9,747,375 bbl. per year, is produced in New York, and the next largest, over 7,202,600 bbl., in Pennsylvania.

The statistics for materials used in the production of malt beverages by breweries in the United States during a typical month—December, 1941—are as follows: Malt, 160,430,301 lbs.; corn and corn products 39,379,740 lbs.; rice and rice products, 12,533,807 lbs.; sugars and sirups, 11,209,084 lbs.; and hops and hop extracts, 2,486.849 lbs.

1. Beer and Ale

Beer and ale are malt beverages, produced by fermentation, each having a characteristic flavor and aroma. They must contain not less than $\frac{1}{2}$ of 1% of alcohol. Their alcoholic content generally ranges between 3 and 6% by volume. Measured in a $\frac{1}{2}$ -in. cell, the color of beer is generally about 4 on Series 52 of the Lovibond scale, although special beers may be as dark as 12. The color of ale is about 5. A gallon of beer or ale weighs $8\frac{3}{4}$ lbs. Beer and ale are similar, but beer is produced by bottom fermentation (although this procedure is not always used), and ale, by top fermentation. The type of yeast used, the temperature of fermentation, and, in rare cases,

bacterial action—all influence the characteristics of the brew. Hind¹ describes the two types of beer as follows:

"Bottom fermentation processes, used for lager beer, differ from top fermentation, adopted for ales, in that the temperature ranges between 41° and 56° F., generally between 42° and 49° F. in Continental practice, while the yeast settles at the bottom of the fermenting vessel at the close of fermentation, instead of rising to the surface of the wort. Fermentation is considerably slower, as a result of the low temperature, than in top fermentation systems. Lengthy storage of the beer between the primary fermentation and racking is normally essential, and gives the name lager or 'stored' to the beer. Fermentation in the storage tanks is due to primary yeast, carried down with the beer from the fermenting vessel. American lager beers are usually fermented almost to the limit and carbonated, either before or after storage. In some cases conditioning is obtained by krausening, or addition of fermenting wort to the storage tanks. Carbonation may be completed with fermentation or tube gas before racking or bottling. Top fermentation beers are carbonated in bulk by similar methods, but it is usual to submit them to a preliminary period of conditioning in tanks at about 60° F."

TABLE 64^a
COMPOSITE ANALYSIS OF BEER AND ALE

Analysis	Beer	Ale
Color, degrees Lovibond.....	4.20	5.11
Saccharometer indication, degrees Balling.....	3.59	3.08
Alcohol, % by weight.....	3.49	4.15
Alcohol, % by volume.....	4.47	5.32
Extract, %.....	5.19	4.95
Reducing sugars, %.....	1.48	1.58
Acidity (as lactic), %.....	0.15	0.17
Protein, %.....	0.36	0.37
pH.....	4.35	4.19
Carbon dioxide, %.....	0.47	0.46
Original gravity, degrees Balling.....	12.0	13.0
Real degree of fermentation.....	56.7	61.9

^a *Am. Brewer*, 75, No. 2, 61 (1942).

There are many types of beers and ales, light and dark, Dortmund, Pilsen, Bavarian, all-malt, Bock beer, half-and-half, and various others not greatly different from the beer and ale already described. Porter is a heavy ale, dark in color, 20 to 40 degrees on the Lovibond scale. Stout is still darker and heavier ale, with a color of 40 degrees or over. Both porter and stout are top-fermented and obtain much of their special characters from heat-darkened malts and caramel.

Beer and ale account for almost all malt beverage production. Composite analyses of these two products are given in Table 64, based on tests of 352 samples of beer and 113 samples of ale. One sample of each of several brands was taken each month during the year 1941.

The general process of producing beer, ale, and similar products is called brewing. Barley malt is first made (Fig. 154) by sprouting grain and drying the malt which develops, among other things, the enzyme, diastase. The malt is dried at about 150 to

¹ H. L. Hind, *Brewing Science and Practice*. Vol. II, Chapman & Hall, London; Wiley, New York, 1940, p. 850.

160° F. for light-colored beers, and up to 225° F. or higher for darker beers, ales, porters, and stouts. The malted barley, the most important ingredient, is ground, mixed with warm water, into a mash. The other ground but unmalted cereals are, when used, boiled in water, cooled, and run into large copper brewing kettles with malt at about 145° F. See Figure 155. During this period the ruptured starch grains are converted

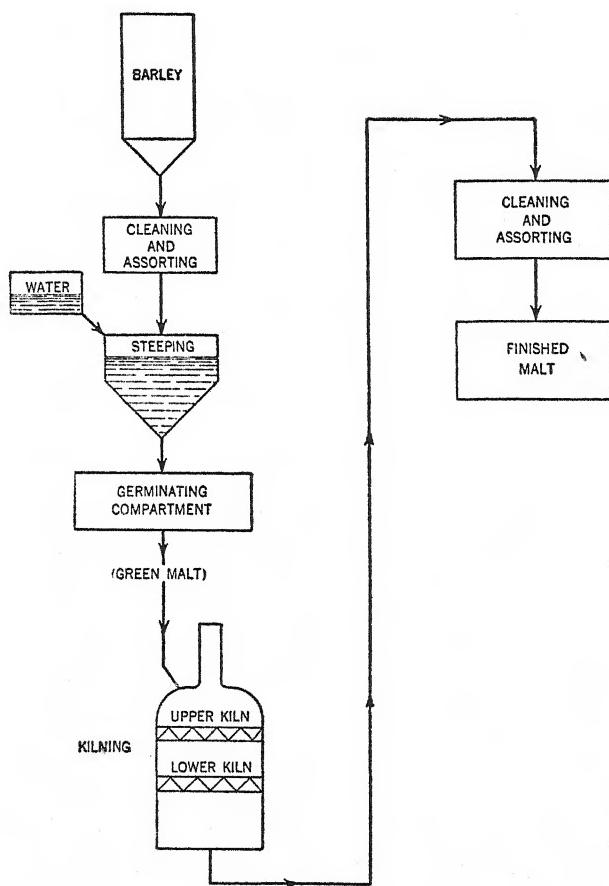


Fig. 154.—Simplified flowsheet of the malting process.^{1a}

into fermentable sugar. This liquid, now called wort, is boiled with 2% or more of hops in a hop jack. The filtered and cooled liquid is then yeasted, and after fermentation is drawn into settling and maturing vats. Some brews retain a great deal of carbon dioxide of fermentation but many must be artificially carbonated to some extent so that they will have the full, standard effervescence before being put into commercial kegs, bottles, and cans. The use of corn products, rice and brewers' sugar as sub-

^{1a} L. Laufer, M. W. Brenner, and S. Laufer, *Proc. Inst. Food Tech.*, 1940, p. 77.

stitutes for malt reduces the content of protein, ash, and phosphoric acid in the finished beer. This difference as regards the protein, ash, and phosphoric acid is sufficient basis for distinguishing all-malt beers made in this country from those containing commercial mixtures of rice, corn cerealin, and brewers' sugar.

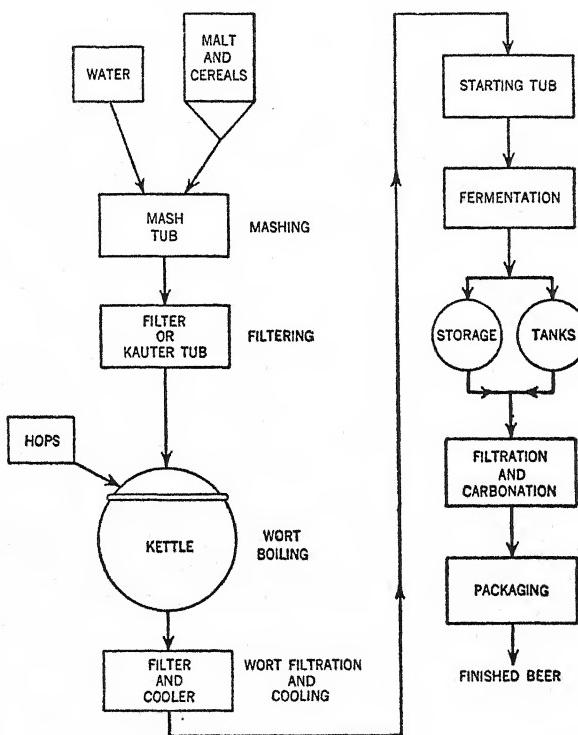


Fig. 155.—Simplified flowsheet of the brewing process.^{1a}

The adulteration of malt liquors appears from the records to be practically negligible. While there is a tendency in comparatively few circles to add as much unmalted cereals and sirups as possible in order to minimize the amount of the more expensive malt needed, even this form of sophistication is relatively insignificant.

2. Special Products

"Cereal beverages" are malt beverages which contain less than $\frac{1}{2}$ of 1% of alcohol by volume. "Malt extracts" are usually heavy-bodied beers.

Sake, the best-known beverage of the Japanese, is a beer produced entirely from rice. Its manufacture consists principally of producing what is called *mushi meshi* by soaking the whole-grain rice until it is quite soft, and then steaming it. The *mushi meshi* is then spread on straw mats to dry partially. About two-thirds of this *mushi meshi*

is made into *koji*, which is mushi meshi to which has been added "mother rice," a culture of a yeastlike fungus or mold. A mixture of mushi meshi, koji, and water becomes the fermenting mass referred to as *moto*. After 10 to 14 days, the completely fermented material is filtered and the resulting clear liquid is called *sei shu* or *maromi*. This fluid is placed in barrels to settle. After a few days the clear liquid is withdrawn and pasteurized and in this state has become sake, which may contain about 17% or more alcohol by volume. Sake is usually stored in specially constructed tubs with solid heads composed of specially selected wood. The principal source of the character of sake is the rapid moldlike fermentation and some flavor obtained from the wood during storage (for labeling purposes sake is classed under F. A. A. regulations as a rice wine).

Pulque is sourish beerlike liquor containing 6% alcohol by volume, produced by the rapid natural fermentation of *aquamiel*, the sweet mucilaginous sap which oozes into the hollowed-out basin of the central bulb of the maguey, or *Agave* (called American aloe or century plant). It is grown principally for this purpose in Mexico, as well as in some Central and South American countries. It is strictly a fermented product and is not distilled. The variety of cactus that produces pulque is entirely different from that from which *tequila* and *mescal* (page 792) is obtained. Pulque is a very low-priced beverage, consumed principally by peons. There are several grades.

II. WINE

The tendency of ancient races to produce pleasant, palatable beverages by fermenting natural products has been almost universal, as shown by the earliest records. The resulting beverages varied widely because of differences in materials available locally. The Egyptians brewed and fermented grain, as did the northern Europeans, who also developed *mead* from honey. The literature of the classic civilizations in the Mediterranean Basin show, however, that wine from grapes was a common beverage and a substantial article of commerce, particularly along the northern and eastern shores.

While earlier wild grapes probably existed, this commerce has for centuries been based on the many grape varieties of the single cultivated species, *Vitis vinifera*, which is today grown commercially in innumerable vineyards (some with over a thousand years of known history) spreading from North Africa to the slopes drained by the Rhine and Danube rivers, and from the Gironde to the shores of the Black Sea. This same species of grape is also cultivated in Asia, its probable point of origin, and has been brought to California, South America, South Africa, and the Antipodes, where, frequently in conjunction with various native species of grapes, it supplies an additional and ever-growing commerce in wine. Basically there are two great families of grape varieties grown in the United States, the one originating from *Vitis vinifera* and cultivated in California and the other, a native American grape, *Vitis labrusca*, grown in other States. About 125 varieties are grown commercially in California, principally for wine purposes, not counting table and raisin varieties.

Legally, the definition of wine in the United States is broad enough to cover all forms of fermentation, both of United States and foreign origin, other than the hop-flavored

malt beverages known as beer, ale, porter, etc. The unqualified term "wine," however, in accordance with common understanding, is limited to fruit juice fermentations, and, more particularly, to grape wine. Wines other than from "the juice of sound, ripe grapes" are always required to show the source of material, e. g., "blackberry wine," "honey wine," "raisin wine." Except where specifically indicated, this section refers to grape wine.



Fig. 156.—Wine map of the United States. (Drawn from data courtesy Wine Advisory Board, San Francisco, California.)

1. Fermentation

The carbohydrate source for the alcoholic fermentation of the grape is its natural content of grape sugar, which consists of about equal proportions of dextrose and levulose. These fermentable sugars also constitute the major portion of the total solids content of the grape.

In complete fermentation, the sugar is converted into almost exactly equal parts of ethyl alcohol and carbon dioxide with very slight amounts of such substances as glycerol and succinic acid also being developed. The carbon dioxide gas bubbles off during fermentation and is lost except when deliberately imprisoned, as in the secondary fermentation of sparkling wines.

The cause of fermentation is amply provided for by nature in all regions in which the grape can be grown to maturity. At this time there accumulates on its skin *Saccharomyces ellipsoideus*, the true wine yeast, containing certain enzymes which catalyze the sugar conversion. Under proper temperature conditions and upon bringing the

wine yeast into contact with the sugar in the juice by breaking the grape skin (as in crushing), fermentation begins. Normally the true wine yeast is present in sufficient quantities to insure a true fermentation and avoid the undesirable fermentations caused by other forms of yeast or by bacteria. However, to attain a satisfactory progress of large-scale operations, it is considered good practice, and, in certain specialized operations such as the secondary fermentation for effervescence of sparkling wines, it is essential to introduce cultivated strains of wine yeast for control of the results.

The amount of alcohol obtained in fermentation depends, first, on the actual sugar content of the grape and, second, on the ability of the particular wine yeast to complete the conversion. In grapes used for wine, the natural sugar content varies widely, ranging from a low of about 14% to a high of over 30%, with an equivalent potentiality for alcohol formation. Exact knowledge of the grape sugar content at the time of picking is, therefore, of prime importance to the wine maker, who, in practice, employs one of several types of hydrometer scaled to show the approximate total-solids content of the juice. This "stem," as it is known, is, in the United States, usually based on the Balling scale, but the Baumé and Brix scales, more commonly employed in Europe, are also used.

The ability of the different strains of wine yeast to survive in the increasing amount of alcohol they create varies. Generally an alcoholic content of between 11 and 14% by volume is all that is achieved (see Table 65); this coincides with the average alcohol potentiality of wine grapes grown in the cooler regions. As a consequence, 14% alcohol by volume is usually regarded for tax and regulatory purposes, as the maximum for completely fermented wines. It is true that in warmer regions, where the grape develops a greater sugar content, completely fermented wines of somewhat higher alcohol may be attained, but usually these grapes are made into partially fermented wines, a good portion of the sugar remaining unfermented so as to render the product sweet to the taste. In sparkling wine production, the effective creation of effervescence by secondary fermentation in the still wine used as a base almost always necessitates the use of yeast strains which can function effectively immediately upon their introduction into the already alcoholic liquid.

Fermentation to an alcohol yield above the potential yield of the natural sugar of the grape has been achieved by using special yeast strains in juice whose sugar content has been augmented by successive introductions of small quantities of condensed grape juice, resulting in an actual yield of 16 to 18% by volume and, under laboratory conditions, of as much as 20% by volume. High alcohol fermentations are not, however, common, because the sugar content of even relatively sweet grapes does not have a sufficient potential yield of both alcohol and residual unfermented sugar, and also because the 200-year-old practice (see page 753) of using wine spirits in the production of sweet dessert wines is a much simpler and more easily controlled practice.

2. Production of Wines under the Internal Revenue Laws

"Pure Sweet Wine" is defined in the Internal Revenue Act of October 1, 1890, as fermented or partially fermented grape juice only. The purpose of the definition was

TABLE 65.—ANALYSIS OF FRUIT JUICES AND WINE MADE FROM THEM IN

Sample consists of	Density	Alcohol by volume, per cent	G. per 100 cc.					
			Solids	Ash	Tannin	Acids		
						Total (as citric)	Volatile (as acetic)	Natural (as citric)
Strawberry juice (Maryland)	1.03877	0	8.71	0.49	0.300	1.46	0.04	1.42
Strawberry wine (Maryland)	0.99855	12.74	3.02	0.38	0.300	1.05	0.03	1.02
Strawberry juice (Dorsett)	1.0434	0	10.30	0.66	0.200	1.02	0.024	0.996
Strawberry wine (Dorsett)	1.0376	12.51	12.80	0.41	0.125	0.75	0.020	0.73
Strawberry juice (Blakemore)	1.0358	0	8.2	0.62	0.220	1.35	0.023	1.33
Strawberry wine (Blakemore)	1.0389	12.30	13.4	0.36	0.125	0.88	0.024	0.856
Cherry juice (Tartarian) (California)	1.07412	0	18.03	0.52	0.110	0.852	0.010	0.842
Cherry wine (Tartarian)	1.00308	12.74	4.11	0.35	0.080	0.585	0.015	0.570
Red raspberry juice	1.0343	0	6.41	0.55	0.200	1.89	0.07	1.82
Red raspberry wine	1.0061	11.33	7.73	0.45	0.250	1.67	0.02	1.65
Elderberry juice	1.03322	0	7.72	0.96	0.500	1.05	0.147	0.90
Elderberry wine	1.00114	11.45	3.97	0.78	0.450	0.72	0.072	0.65
Virginia (early peach juice)	1.04522	0	10.81	0.52	0.055	0.455	0.022	0.433
Virginia (early peach) wine No. 5	1.0472	10.57	14.70	0.37	0.045	0.455	0.035	0.420
Maryland peach juice, No. 1 Fireglow	1.04324	0	9.89	0.49	0.030	0.598	0.007	0.591
Maryland peach wine, No. 1	0.99331	12.55	1.80	0.25	0.040	0.553	0.014	0.539
Maryland peach juice No. 2 (Golden Globe)	1.04287	0	9.91	0.51	0.040	0.620	0.012	0.608
Maryland peach wine No. 2 (Golden Globe)	0.99309	12.83	1.79	0.26	0.035	0.602	0.014	0.588
Maryland peach juice No. 3 (Halehaven)	1.04634	0	10.85	0.45	0.040	0.459	0.012	0.447
Maryland peach wine No. 3 (Halehaven)	0.99397	11.59	1.67	0.22	0.040	0.504	0.012	0.492
Maryland peach juice No. 4 (Golden East)	1.03653	0	8.45	0.49	0.090	0.360	0.012	0.348
Maryland peach wine No. 4 (Golden East)	0.99417	11.92	1.85	0.26	0.045	0.518	0.015	0.503
Maryland peach juice No. 6 (Alberta)	1.04427	0	10.24	0.42	0.090	0.500	0.013	0.487
Maryland peach wine No. 6 (Alberta)	0.99388	12.44	1.82	0.27	0.050	0.537	0.016	0.521
California plum juice (Duarte)	1.04970	0	11.06	0.59	0.030	0.878	0.007	0.871
California plum wine (Duarte)	0.99976	12.03	2.74	0.39	0.040	0.616	0.011	0.605
California grape (juice) (Thompson seedless)	1.08534	0	20.1	0.39	0.025	0.780	0.007	0.773
Thompson seedless wine	0.99854	10.85	1.90	0.45	0.080	0.894	0.010	0.884
California grape (juice) (red Malaga)	1.07585	0	17.2	0.50	0.025	0.534	0.007	0.527
Red Malaga wine	0.99869	9.88	1.63	0.42	0.075	0.615	0.014	0.601

ALCOHOL TAX LABORATORY, WASHINGTON, D. C., 1941-1942^a

Nitrogen as protein	Phosphates as P_2O_5	Alkalinity of water-sol. ash, cc. N/10 H_2SO_4 per 100 cc. wine	Hamil-Simonds or chromatic absorption	Color "as is" in $\frac{1}{8}$ -in. cell (Lovibond)	Other information
0.250	0.029	63	Blue	2.4 Red (off shade)	In the case of grape wine only the total and natural acids are calculated as tartaric
...	0.030	42	Blue	1.2 Red	Ordinary market strawberries purchased in Washington, D. C. Pure filtered juice analyzed
0.224	0.352	67	Blue	8.5 Red 8.5 Brown	The whole crushed strawberries were ameliorated with 35% sugar and water before fermentation
0.071	0.021	44	Blue	0.9 Red 2 Brown	Dorsett strawberries grown at U. S. Hort. Center, Md., 1942. Pure filtered juice analyzed
0.166	0.375	62	Blue	6.5 Red 10 Brown	This wine was made according to A. T. Circular 621—as standard strawberry wine
0.061	0.021	40	Blue	0.9 Red 2 Brown	Blakemore strawberries grown at U. S. Hort. Center, Md., 1942. Pure filtered juice analyzed
0.894	0.047	..	Dull yellow	5.5 Red 15.0 Brown	This wine was made according to A. T. Circular 621—as standard strawberry wine
0.320	0.034	37.0	Dull golden yellow	2.0 Red 7.5 Brown	The pure filtered cherry juice analyzed. Tartarian cherries, grown in California, in 1941
0.304	0.0545	..	Blue	4 Yellow 46 Red	The whole crushed cherries were ameliorated with 35% of the resultant volume with sugar and water before fermentation, 1941
0.145	0.020	44.3	Blue	3 Brown 17 Red	Red raspberries grown in 1941, U. S. Hort. Center. Pure filtered raspberry juice analyzed
0.97	0.075	69.5	Blue	50 Red ($\frac{1}{8}$ -in. cell)	The whole crushed raspberries were ameliorated with 35% of resultant volume with sugar and water to produce not over 13% alcohol by volume
0.88	0.044	52.0	Blue	29 Red, 0.4 bl. ($\frac{1}{8}$ -in. cell)	Juice from whole frozen elderberries obtained from Pittsburgh, Pa., 1942
0.413	0.018	61.0	Yellow	Pale peach color	Wine made in accordance with A. T. Circular 621
0.140	0.009	40.0	Yellow	Pale peach color	Early Virginia peaches (small) grown near Charlottesville, Va., July, 1942. Pure filtered juice analyzed
0.402	0.028	44.5	Yellow	($\frac{1}{8}$ -in. cell) 2 Brown	Wine made in accordance with A. T. Circular 621, 1942
0.153	0.016	30.3	Yellow	Pale peach color	These peaches were obtained from U. S. Hort. Center, Maryland, Aug., 1942. The juice filtered and analyzed
0.350	0.027	47.0	Yellow	($\frac{1}{8}$ -in. cell) 5 Brown	Wine made in accordance with A. T. Circular 621, 1942
0.111	0.015	31.7	Yellow	Pale peach color	These peaches were obtained from U. S. Hort. Center, Md., Aug., 1942. The juice was filtered and analyzed
0.411	0.029	39.0	Yellow	2 Brown ($\frac{1}{8}$ -in. cell)	Wine made in accordance with A. T. Circular 621, 1942
0.166	0.016	25.4	Yellow	Pale peach color	These peaches were obtained from U. S. Hort. Center, Md., Aug., 1942. The juice was filtered and analyzed
0.339	0.024	45.0	Yellow	3.5 Brown ($\frac{1}{8}$ -in. cell) Pale peach color	Wine made in accordance with A. T. Circular 621, 1942
0.148	0.014	32.1	Yellow	Pale peach color	Wine made in accordance with A. T. Circular 621, 1942
0.287	0.029	45.5	Yellow	0.4 Red 7.5 Brown ($\frac{1}{8}$ -in. cell)	The peaches were obtained from U. S. Hort. Center, Md., Aug., 1942. The juice was filtered and analyzed
0.092	0.017	32.5	Yellow	Pale peach color	Wine made in accordance with A. T. Circular 621, 1942
0.465	0.050	58.0	Yellow	0.5 Red 4.5 Brown ($\frac{1}{8}$ -in. cell)	These plums were grown in California in 1942. The juice was filtered and analyzed
0.067	0.017	40.0	Yellow	2.5 Brown ($\frac{1}{8}$ -in. cell)	Wine made in accordance with A. T. Circular 621, 1942
0.114	0.030	35.0	Yellow	0.2 Red 0.5 Brown	These grapes were obtained from California in August, 1942. The juice was filtered and analyzed
0.117	0.036	34	Yellow	3 Brown (1-in. cell)	Wine made by crushing and fermenting whole grapes without addition of sugar or water
0.310	0.060	41.0	Yellow	0.4 Red 1.5 Brown	These grapes were obtained from California in August, 1942. The juice was filtered and analyzed
0.177	0.046	35.5	Yellow	4.5 Red 3.8 Yellow	Wine made by crushing and fermenting whole grapes without the addition of

to set a standard for wine eligible for the addition of wine spirits. This act was amended on August 27, 1894, to make provision for the addition of pure boiled or condensed grape must or pure crystallized cane or beet sugar, or pure dextrose sugar, or water, for the purpose of perfecting sweet wine according to commercial standards. The amount of added sugar may not exceed 11%, and the amount of water may not exceed 10%, of the weight of the wine. This method of wine making is used almost exclusively by California wine makers in producing grape wine (except that State law forbids the addition of sugar). Eastern wine makers for many years claimed that, because of the high acid and low sugar content of their grapes, a satisfactory wine could not be made by them under the limitations imposed by the Act of October 1, 1890, as amended.

In 1916 provision was made in internal revenue law for the use of a sugar and water solution in the production of "Natural Wine" (Public No. 271—approved September 8, 1916). The provisions were re-enacted in the Revenue Act of 1918, which authorized wine makers to label their products as standard wine even though a sugar and water solution was added in the production of wine from grape juice, provided the resultant product contained at least five parts per thousand of acid before fermentation and not more than 13% alcohol after complete fermentation, and the sugar and water solution did not in any event increase the volume of the resultant product more than 35%. In addition, wine makers were authorized to sweeten the wine under limitations applicable to "pure sweet wine."

The provisions of internal revenue law relating to "Natural Wine" (grape wine) were extended to wines made from citrus fruit (except lemons and limes) by Section 11 of the Federal Alcohol Administration Act, approved August 29, 1935; and in addition thereto citrus fruit wine makers were authorized to add dry cane, beet, or dextrose sugar for the purpose of perfecting the product according to standards.

Section 330 of the Act of June 26, 1936, extended the provisions of law relating to "Natural Wine" and citrus fruit wines to wines made from many other fruits (including berries). The provisions were extended by the Act of June 15, 1938, to additional fruits, including plums, pears, and prunes, and by the Act of April 20, 1942, to pineapple, papaw, papaya, and cantaloupe.

3. Classification of Wines

The varieties of wine are almost as innumerable as nature, coupled with human ingenuity, could possibly make them. The seeming complexities are, however, details within the following broader methods of identification.

(a) Identification by General Class Characteristics

General class characteristics are readily identifiable by tests of the finished product. These may be made in the laboratory by chemical and physical analyses, or they may be made organoleptically, *i. e.*, by application of the senses of sight, taste, and smell. The first method is usually used as a control device in actual production and also to

assist in the detection and prosecution of the grosser forms of adulteration. The latter method is the customary way of evaluating wine among the trade and by consumers. When employed by an expert with a sensitive palate, a large experience in the comparison of wines, and a well-trained taste memory, the organoleptic method has even been recognized as evidence in criminal and civil courts, particularly in Europe. The two methods supplement each other, are not in conflict, and are frequently combined. The former naturally applies only to detection of matter analytically measurable and has the advantage of presenting comparative conclusions in relatively exact terms. The latter evaluates factors that cannot be detected by analysis, as well as those that can, but does not express comparative conclusions with exactness.

The general class characteristics of a wine are established by its color, by its relative sweetness and alcohol content, by its effervescence or noneffervescence, and by its conformity or nonconformity to accepted standards.

Color.—Grape wines are either red or white or, in certain cases, a combination of the two, known as rosé or pink.

The red color of grapes is caused by anthocyanin, a pigment in the skins of the purple or red varieties. By permitting the skins of the freshly crushed grapes to remain with the juice during the first period of fermentation, the alcohol of fermentation draws the pigment out. The degree of color obtained depends on the length of contact with the newly fermented juice and on the quantity of available color in the skins of the particular variety. Varieties excellent in all characteristics except color are often blended with other varieties having strong available pigmentation in order to insure uniformity in this respect.

White wines are those which contain no red coloring matter, effected either by pressing off the juice of dark-skinned grapes and fermenting the grapes without contact with the skins, or by using white-skinned grapes. While called white, neither the wine nor its original juice is ever actually water-white, but varies from a pale straw color to gold or pale green, or, when given certain treatment as in the case of sherries, to a light or deep amber.

Red wines vary considerably in their power to retain their pigment, depending on the particular variety of grape used and upon the length of storage in cask or bottle. "Tawny port" is an example of a wine that has "cast" part of its original ruby hue. Some wines made on the skins of grapes ill adapted for red wine may assume a pale amber color in a relatively short time. Pink or rosé wines are a combination of red and white made either by leaving the purple skin in the fermenters for only a short period or by blending white wines with a small proportion of red; these have achieved some popularity for "pink champagne" (known to the French as *oeil de Perdrix*) and also for light still table wine.

Sweetness and Alcohol Content.—Wines may be either "dry" (*i. e.*, containing little or no unfermented residual sugars) or "sweet."

Since fermentation uses up the grape sugars, the former class comprises wines in which fermentation has been completed or practically completed and which contains all the natural alcohol of which the particular grape is potentially capable; as already

mentioned, this alcohol may range from 7% to as much as 16% by volume, but is usually between 12% and 14% by volume.

Sweet wines, then, are the result either of partial fermentation only or of complete fermentation coupled with the addition of unfermented juice or unfermented condensed juice. Where no wine spirits are added, the alcohol of the finished product will (because grapes somewhat sweeter than those employed for dry wines were used) be about 11 to 14% by volume with about 2% to more than 4% of unfermented sugar, as in the case of the slightly sweet and sweet sauterne.

Where the alcohol and sugar contents are both high, usually there has been a partial addition of wine spirits for the purpose of retaining a portion of the grape sugars in an unfermented form, and there may also have been a further addition of unfermented juice or of unfermented condensed grape juice to increase the unfermented residual sugar content. Such products, for example, ports and sherries, may be relatively dry or relatively sweet, although in all cases they contain some residual grape sugar. The alcoholic range of this third group of products is usually between 19 and 21% by volume.

It is thus impossible adequately to describe a wine by the simple statement that it is sweet or dry or by simple reference to the statement of alcohol content on its label. The combination of the two, however, is informative; and in recent years in the United States, following earlier custom abroad, the terms "table" wine and "dessert" wine have become established—the former applying to wines having not more than 14% alcohol by volume and being either dry or somewhat sweet, and the latter applying to wines with an alcoholic range of over 14% by volume, but not over 21% by volume, with a minimum sugar content that varies with the particular type.

A variant of the dessert wine classification is the group of wines known as "appetizer" wines. Into this class fall the drier, noticeably rancio-flavored sherries, and the aromatic-flavored "aperitif" wines, of which vermouth is the best-known type. Because of their slight, pleasing astringency, these appetizer wines are more readily suited for before-meal consumption than the other, blander types of dessert wines.

The so-called "blending" or "industrial" wines, having an alcoholic range of over 21% by volume but not over 24% by volume, and with a sugar content sometimes as high as 20° Balling, are not often consumed, but are used primarily for blending in small quantities with dessert wines slightly deficient in sugar or alcohol, or for sale to pharmaceutical houses and bakeries.

Effervescence or Noneffervescence.—Both the table wines and dessert wines already discussed are "still" wines, retaining none of the carbon dioxide gas created in the fermentation. This carbon dioxide gas can be retained, however, by bottling or otherwise sealing the container of fermenting wine. This may happen accidentally, as in bottling a table wine too soon, when all its sugar has not been entirely consumed. Such wines, as a rule, do not have sufficient remaining sugar to produce much carbon dioxide. In practice, "sparkling" wines are made by adding to a still table wine a calculated amount of sugar together with a special strain of wine yeast which, when the wine is bottled or otherwise sealed, will create a substantial amount of carbon di-

oxide gas but not enough to break the container. The term "sparkling" applies, then, to wines which have a substantial effervescence created by fermentation in a closed container, tank, or bottle. Sparkling wines generally have an alcoholic content of 12 to 14% by volume and develop an internal pressure of 60 to 90 lbs. per sq. in. at normal cellar temperature. Champagne, a white sparkling wine, is of course the leading type of this class. The very slightly effervescent wines are known to the French as *petillant*.

In all countries some effervescent wines are made by artificial impregnation with carbon dioxide, but these are differently designated than the naturally sparkling wines. In the United States "carbonated wine" is the prescribed term.

Conformity to Accepted Standards.—The term "sound" is one applied to wines free of the diseases and other defects found in badly made wines or in wines made from substandard material; it is not an indication of grade or quality. The term "substandard" applied to wines spoiled, adulterated, or made from substitute or sub-standard materials. Wine-consuming countries, including the United States, protect the buyer against substandard wines. They do not, however, necessarily require conformity to a minimum grade or quality except when a particular wine description is used which has become associated with a given standard of grade or quality, usually developed by local effort over a period of time.

(b) *Identification by Origin*

"Origin" means the viticultural area, where the grapes are grown, and in or near which the actual production of the wine takes place. The value of the "appellation of origin" for classification purposes is based on the fact that the climatic and soil conditions of the place of growth are largely determinative of the year in, year out characteristics of any given grape; for example, the "mourastel" grape when grown in the warm fertile regions of southern France may produce a grape suitable, by reason of its sugar, acid, and other components, for use only as a blending wine, whereas, when grown in the Livermore Valley of California, its balance of these components may render it more suitable for a light table wine.

The appellation of origin applied to the wine may describe either a very large area (e. g., "Ohio") or a very small area, as the name of a district or even of a vineyard. It is not, however, used as the sole description of a wine except in the case of a relatively small area and then usually only when the area named has concentrated over a period of time on the production of one kind, or a few very closely related kinds of wine, usually made by all the producers in the area from certain specific grape varieties that have been found after many years of experimentation to be most suitable for wine production there. For example, the unqualified term "port" (corrupted from *Oporto*) signifies the usually red, though sometimes white, Portuguese dessert wines grown in a fairly large but definitely restricted area inland from the shipping city of Oporto on the upper regions of the Douro River. A similar situation exists with respect to the unqualified term "sherry" (corrupted from *Jerez*), grown in a fairly large area on the

southwest coast of Spain, inland from Cadiz. In regions where wine production has not become so highly specialized as to type, the appellation of origin is highly informative when placed in conjunction with some other description of the wine (*e. g.*, "French Red Table Wine," "Southern California Red Dessert Wine") and is usually required when the other description is a term referring a wine originally derived from some other region (*e. g.*, "Australian Burgundy," "New York State Port").

All wine-producing countries afford protection to their own wine appellations of origin and, occasionally, under treaty, to those of other countries. An example of the latter is the English requirement limiting the term "port" to wine certified to be such by the Portuguese Government. Examples of the former vary considerably, because established local wine-making practices may to some extent be based on the partial use of grapes from similar adjacent regions. For example, the French Government has several times expanded slightly its definitions of the champagne district, and the German Government, although rigid about its requirements for actual district or vineyard names, has permitted the term *liebfraumilch* to be applied to wines of a certain type produced in the Rheinhesse area from grapes of whatever origin but similar to those locally grown. In the United States, the Federal Government permits producers in any named area to bring in from other areas up to 25% of their grapes unless local law denies such permission; such additional local restrictions are enforced federally in the interstate commerce in wine, as in the case of California's requirement that wine designated as "California" be made from California grapes only.

(c) Identification by Grape Variety

Given the proper district of origin for its best growth, the varietal name of the grape employed also has value in describing the wine, particularly if the grape has marked distinguishing characteristics or reputation for quality. The grape variety is not usually named when the wine is a blend of several different grapes, when its product is not markedly different from other similar local wines made from other varieties, or when the wine maker prefers to blend his wines to a uniform standard of taste and quality demanded by his trade regardless of variety or district.

The number of grape varieties is legion but certain varieties have achieved prominence in the United States. Among the *vinifera* varieties are: the Riesling (including the Johannisberger Riesling and the Sylvaner or Franken Riesling) and the Traminer; the Pinot (including the Pinot Noir and the Pinot Chardonnay) and the Gamay; the Semillon, the Sauvignon, the Cabernet or Cabernet-Sauvignon, and the Muscadelle de Bordelais; the Palomino and the Pedro Ximénez; the Barbera; the Muscat (of which there are many subvarieties); the Zinfandel. Native American varieties include Elvira, Catawba, Delaware, Eumelan, Norton, Ives, and Scuppernong.

The Federal Government forbids the application of any grape name to a wine unless the predominant characteristics of the wine come from that variety, and, to insure this, it also requires that at least 51% of the volume of the wine be derived from that grape. Any additional local requirement of a higher grape content of the named variety is, however, enforced federally in the interstate commerce of wine.

(d) Identification by Semigeneric Description

As stated above, certain wine-producing regions have, over a period of time, come to produce wines of such uniform and distinctive characteristics that the name, or derivative of the name, of such regions has become recognized generally as the sole name of the wine. Examples are sherry (light or dark amber dessert wine from Jerez), port

TABLE 66

THE 72 TYPE NAMES MOST FREQUENTLY APPLIED TO WINE IN THE UNITED STATES^a

(The 12 most popular distinct types are in capital letters; grape names are italicized)

Appetizer Wines

SHERRY	VERMOUTH	Madeira	Marsala
<i>Red Table Wines</i>			
CLARET	<i>Cabernet</i>	<i>Durif</i>	<i>Norton</i>
BURGUNDY	<i>Carignane</i>	<i>Gamay</i>	<i>Petite Sirah</i>
<i>Barbera</i>	<i>Charbono</i>	<i>Grignolino</i>	<i>Pinot Noir</i>
Barberone	<i>Chianti</i>	<i>Ives</i>	<i>Zinfandel</i>
Aleatico	<i>Concord</i>	<i>Mourastel</i>	
<i>White Table Wines</i>			
RHINE WINE	<i>Chardonnay</i>	<i>Light Muscat</i>	<i>Sauvignon Blanc</i>
SAUTERNE	<i>Delaware</i>	<i>Malvasia Bianca</i>	<i>Scuppernong</i>
Dry Sauterne	<i>Elvira</i>	<i>Moscato Canelli</i>	<i>Semillon</i>
Sweet Sauterne	<i>Folle Blanche</i>	<i>Muscat Frontignan</i>	<i>Sylvaner</i>
Haut Sauterne	<i>Golden Chasselas</i>	<i>Moselle</i>	<i>Traminer</i>
Chateau Sauterne	<i>Gutedel</i>	<i>Pinot Blanc</i>	<i>Ugni Blanc</i>
Catawba	<i>Hock</i>	<i>Riesling</i>	White Chianti
Chablis	<i>Rosé or Pink</i>		
<i>Sweet Dessert Wines</i>			
PORT	WHITE PORT	Malaga	Red Muscatel
MUSCATEL	<i>Angelica</i>	<i>Malvasia</i>	Sweet Sherry
TOKAY	<i>Aleatico</i>	<i>Muscat Frontignan</i>	
<i>Sparkling Wines</i>			
CHAMPAGNE	Sparkling Sauterne	Sparkling Muscat	Sparkling Moscato
SPARKLING BURGUNDY	Sparkling Moselle	<i>Moscato Spumante</i>	<i>Canelli</i>
Pink Champagne			

^a Based on "Wine Growing and Wine Types," Wine Hand-Book Series 2, Wine Advisory Board.

(red, tawny, or white dessert wine from Oporto), champagne (white sparkling wine from the district of that name on the Marne), Burgundy (red or white table wine from the Bourgogne district of eastern France), sauterne (white table wine, usually slightly sweet, from Bordeaux), claret (applied to the red table wines of the Bordeaux), Chablis (white table wine from the district north of Bourgogne), Rhine wine (or hock), Moselle, Chianti, etc.

The well-understood and sharply marked differences in characteristics among the wines of these European areas very naturally resulted, within the newer wine-producing areas, in a tendency to describe the latter's products in similar terms, as these terms provided a ready, common denominator of understanding between the wine maker

and his customer. In the United States, federal regulation permits a limited number of such terms on wines of other origin but only when the actual place of origin is also shown, and also only when the wine actually conforms in its general characteristics and method of production to its prototype, *e. g.*, American sherry, Argentine champagne, Australian hock, etc. Without a declaration of actual origin, the use of these terms is forbidden in the United States and in most wine-consuming countries. In the United States, the use of any geographic terms other than the limited number of distinctive names specifically authorized is also forbidden, regardless of attempt to qualify as to actual origin. Among some countries, treaties exclude any use of the other's wine appellations of origin—for example, Portugal and France.

The foregoing four methods of describing wines may be used separately and are sometimes used in combination; for example, "Napa Valley Traminer—a California Table Wine Made from the Traminer Grape of the Rhine Grown in the Napa Valley." More usually United States wines are sold simply as "California Zinfandel," "Ohio Port," "Livermore Valley White Wine," or "New York State Sherry." The use of the names of the more expensive grape varieties has recently, however, become somewhat more common on the labels of American wines.

In the United States, the Wine Advisory Board² has grouped wine into five classes: white table wines, red table wines, dessert wines, sparkling wines, and appetizer wines. In the five classes of wine there are 12 distinct wine types well known in the United States: sherry, Rhine wine, port, muscatel, Tokay, white port, claret, Burgundy, sauterne, vermouth, champagne, and sparkling Burgundy. Table 66 lists 72 names of wine types most commonly encountered in stores and which fit into the five classes named above.

In conclusion, the wine maker, or the bottler of the wine, uses a considerable variety of nomenclature depending on the nature of the product or products he has to sell and the particular kind of trade he is trying to reach. There are definite legal limitations as to meaning of all the terms he uses, but he is permitted a great deal of freedom of selection. See Regulations No. 4, Bureau of Internal Revenue.

4. Production of Table Wines

The successful production of a particular type of table wine depends upon proper selection from among the grape varieties available to the wine maker, and upon picking them when their sugar and acid contents are at the right stage. The principal acid in grapes is tartaric acid, and is relatively low when the sugar content of the grape is high and relatively high when the sugar content of the grape is low.

In general, for dry table wines a sugar content of not over 22° Balling and an acid range of from $5\frac{1}{2}$ to 8 parts per thousand are desirable; if the grapes are slightly deficient in acid, it is permissible in most countries to correct the juice by the addition of tartaric, citric, or malic acids. Deficiency of acid in finished wine renders it insipid;

² Wine Advisory Board, 85 Second Street, San Francisco, California.

excess acid renders it too fresh and tart. A proper balance in the finished wine of alcohol and acid, and also of unfermented residual sugar in the case of the sweeter table wines, constitutes the basic requirement for soundness and palatability. The additional factors that make for extra quality depend upon use of the better wine grape varieties, the skill of the particular wine maker in handling the product during its fermentation, and its subsequent aging in cask and bottle.

A natural formation of large amounts of glycerol is desirable to give "body" to the sweeter white table wines. A naturally high tannin content is desirable for slight astringency in the rougher red types (for example, Chianti), the tannin being derived principally from the skins and seeds. For the more full-bodied table wines (for example, a Burgundy type as distinguished from the lighter-bodied claret type) a relatively high "extract," that is, nonsugar, soluble solids content, is desirable.

Any given vineyard necessarily varies to a greater or less extent each year in regard to the relative components of the particular variety of grape which it produces. In districts of relatively even climate these successive annual differences are not important, except where the production of finest quality wines is concerned. Where sharp variations in climate occur, however, the annual changes may result in a wine of fine quality one year and a poor or even a bad wine the next. The practice of "vintage dating" wine with the year of the crop from which it is made is thus of significance only when the district of growth is also stated, and of importance only when the annual variations in that district are substantial.

Immediately after picking, the grapes are brought to the winery as soon as possible. Usually local practice regards the stems as giving excessive astringency, so they are removed first. In the case of red wines, the grapes are crushed and transferred to the fermenters—juice, skins, pulp, and seeds together. The pressing occurs after fermentation is completed and to the extent necessary to recover the fullest quantity of fermented juice from the "pomace" (remaining skins, pulp, and seeds; also known, particularly when pressed, as "marc" or "cheese"). In the case of white wines, pressing takes place before fermentation; and the "free-run" juice, together with an amount of subsequently extracted pressed-out juice, goes to the fermenters without contact with the pomace.

Wine makers' practices of fermentation and subsequent cellar treatment of wines vary enormously, actual local experience over periods of years and even centuries giving authoritative weight, and in some instances a superstition, to the local desirability of particular practices. For example, in modern times such wide variations as these are found between the time of picking and the time of fermentation:

- (a) The grapes are brought by hand in baskets to low, open, stone or concrete fermenting vats where they are trodden out by foot.
- (b) The grapes are carefully packed in layers separated by clean cheesecloth in a large hand press, the earlier free-run juice being kept separate from the juice last pressed out and the two lots of juice mixed together in the fermenter in the exact proportions desired.
- (c) The grapes are deposited in a hopper which passes them through a centrifugal stemmer and crusher that separates the stems and passes the crushed juice and pomace by pipe line to the fermenters.

(d) After extraction of the first juice, the pomace is run through an Archimedes screw which extracts the last bit of liquid from the now sawdustlike pomace.

It is impossible to comment adversely or favorably on any of these or the many other variable winery practices without knowing the potential wine quality of which the particular grapes are capable, the relationship of labor supply and other costs to the maximum price which the particular wine will command on the market, and the particular type and quality of wine desired. In general, nearly all winery practices have their useful and proper place, as have all sound wines, regardless of quality.

In fermentation, wine usually passes through two stages. Primary fermentation usually lasts 4 to 10 days, during which practically all of the sugar is converted into alcohol, and after which the fermented juice must be transferred (or "racked off") to other casks or tanks so as to separate it from the major portion of the pomace and solid matter that was with the juice in the fermenters. This primary fermentation takes place in ample contact with the air, the oxygen of which facilitates fermentation, at temperatures best suited to the most active function of the yeast (around 80° F., temperatures below 70° slowing down the enzymic action, and temperatures of 100° inhibiting such action). The fermenters used range from vast, open concrete tanks to 50-gal. barrels with only a bunghole opening. In general, red wines are initially fermented in containers with wide openings, the pomace "cap" being held under the top of the wine to which it tends to float, and white wines in containers permitting only a relatively small exposure to the air.

Subsequent fermentation continues slowly after the first racking and for so long as any fermentable sugars remain. This period usually lasts until the following spring. The containers during this period are closed in a manner permitting the carbon dioxide gas to escape, but not permitting the entrance of any quantity of air that might in turn introduce undesirable organisms which would transform the fermentable material left in the wine and cause its spoilage. Occasional rackings during this period are sufficient to reoxygenize the wine yeasts.

In general, table wines are ready for bottling from the storage tanks or casks when they have completely fermented and have been completely separated, by racking and, in the final stages, by "fining" (see page 28) or filtration, from their yeasts and from the remaining solid matter of the grapes which accompanied the juice in fermentation. During storage, however, the acids, alcohols, and extracts, assisted by oxygen, tend to form certain other combinations which, with the better variety of wine grapes coming from the districts most favorable to their growth, ultimately develop the fullest flavor, aroma, and vinosity. Furthermore, this process, if the wine is suited to it, continues, in the bottle although with less oxygen and at a slower rate. The wine maker must, therefore, decide how long he will leave the wine in cask and, after bottling, how long he will "bin" it in its bottle before releasing it for consumption. Obviously, only wines with high potentiality for flavor and aroma and commanding a substantial price on the market are worth barreling and binning for long periods of time. In general, the better quality of red table wines are kept in cask or barrel or oak or redwood storage tank for 2 to 4 years before bottling, and white wines somewhat

less, with a period afterward of improvement in the bottle of from some months to a number of years. This period of improvement in wood and bottle definitely has no relation to the time involved, but depends entirely on the characteristics of the particular wine, which, if overaged, would become flabby and insipid, with sometimes separate deterioration of its aroma and flavor. Thus, while year of growth and district may have some bearing on quality, age, as such, has not.

The production of slightly sweet or sweet table wines involves a high degree of ingenuity on the part of both man and nature. Since the alcoholic content of these types, such as the sauterne, is 12 to 14% by volume, obviously a somewhat greater degree of sugar content is called for than in the ordinary dry table wine grape. In general, the following methods are employed:

1. The *Botrytis cinerea* mold, naturally present at maturity in certain vineyard areas such as the Sauterne District of Bordeaux, causes tiny holes in the grape skin through which the water in the grape evaporates, resulting in a relatively high sugar content; the grapes are then picked, crushed, and fermented off the skins at a slow rate, fermentation being halted either by agitation or introduction of sulfur dioxide at the proper alcohol content, leaving the desired amount of unfermented residual sugar, which is then carried with the wine during its entire storage period under circumstances naturally requiring extreme care to avoid re-fermentation or off-fermentation. This method has been employed in the past only for the most expensive sauterne, and then only in unusual years when conditions have warranted such production.

2. The white wine is fermented off the skins completely dry, but a certain amount of juice from the same grapes is saved aside unfermented (*muste*) and, either in its natural condition or in a slightly condensed form, is re-added to the wine either at a point in storage when the wine has been cleared of all active yeasts or later shortly prior to bottling.

3. Certain of the grapes are partially dried on mats to secure a reduction in their water content and proportionate increase in their sugar. The juice from these grapes is then mixed in a predetermined quantity with the freshly picked grapes to obtain a juice of high sugar content. The juice is handled as previously described. This method is employed in making the sweet white table wines of the Hungarian district of Tokay.

There are many variants of the foregoing processes described for dry and sweet table wines, but they all involve the same essential determinations: quantity of sugar in juice to be fermented; quantity of alcohol to be contained in the finished product; quantity of residual unfermented sugar, if any, to be contained in the finished product; color; and acid. These determinations are based on the natural capabilities of the grape variety or varieties available.

(a) Commercial Production

The crushed grapes and their juice, commonly called "must," are pumped into fermenting vats where they are allowed to ferment, either with the yeast naturally present or with a prepared yeast culture, until, for dry table wine, all the sugar of the must is exhausted. As noted previously, red wine is usually fermented with the pulp and skins of the whole grapes, the natural pigments from the skins entering the wine and giving it color. White wine is made from the fermentation of the juice alone, drawn off from

the grapes immediately after crushing. After fermentation, the wine is drawn off or pressed from the solids. When some sugar is to be left in the wine, as in the production of dessert wines, fermentation is arrested while the desired amount of natural grape sugar remains. A general practice, in the case of dessert wines only, is to add grape brandy which has been distilled at high proof. The new wine after fermentation is transferred at once into storage casks where it may remain, as described above, for months or years, or it may be transferred periodically from one storage tank to another. During the storage period the wine casts down grape solids, foreign particles, and cream of tartar. This settling is more extensive for new wine but continues to some extent in older wines as well. The transferring of wine from one storage tank to another away from the sediment, or "lees," is known as the racking process.

Red Table Wines.—The storage casks must always be kept filled with the same kind of wine, in order to avoid excessive oxidation and vinegar formation.

Principally for the sake of uniformity, but for numerous other reasons as well, most table wines are blended. In order to make the wine as attractive as possible, refrigeration, clarification, and filtration are practiced. Most red table wines are fermented completely dry and, on account of the effect of the fermentation on the grape skins, may have astringent or tart flavors and much of the character of the original grapes. Most red table wines are made from two or more, often several, grape varieties. Sometimes the juices are blended before fermentation, but usually the wines of different grape varieties are blended after having been fermented and racked.

The principal grapes used in California for red table wines are Zinfandel, Carignane, Petite Sirah, Grenache, Barbera, Alicante Bouschet, Cabernet Sauvignon, Pinot Noir, and many others. There are usually about 25 common California black grapes which are made into red table wines. In the East, the principal grapes used for red wines are the Concord, Norton, Clinton, Ives, Isabella, Delaware, Fredonia, Catawba, and numerous others in smaller quantities.

The Concord, Ives, and Clinton grapes, usually hot pressed (140° F.), form the basis of most of the color or red wines of the East. The eastern black grapes are also fermented on the skins to produce red wines.

Claret.—Claret is a red wine, beautifully clear in color, although not the darkest of the red wines. It originated in the coastal wine regions of France, in Bordeaux, and other near-by wine regions where hundreds of millions of gallons of red wine are produced in normal times. The Cabernet Sauvignon is the most important grape used for claret in France but it is often blended with smaller amounts of wine from one or more other native red grapes. The alcohol in these wines is generally less than 12% by volume. These wines are seldom kept in wood more than three years. Large amounts of claret wines are also produced in South America and Australia.

In California, claret is any light-bodied red table wine of good or medium quality, the term being used in contradistinction to Burgundy, the latter being heavier and darker red in color, although the same grapes may be used to produce it. In California, the principal grape for claret is the Zinfandel although red wines from nearly all the California red grapes, including the California-grown Cabernet Sauvignon,

may be used in various quantities in blending. The grapes for California claret are principally those grown in the northern and coastal counties of California.

Claret in the East is produced as the result of fine blending of eastern wine, the Concord, Ives, Norton, and Clinton furnishing most of the color.

White Table Wines.—Such wines vary from those dry and tart in character to those mild and delicate in flavor. Like the red wines, the natural alcoholic content of white table wines is from 10 to 14% by volume. Their color will range from pale straw to deep gold. As the claret and Burgundy are the most popular of the commercial red wines, so sauterne and Rhine wine are the most popular of the white wines. As mentioned, the making of white wine differs from that of red in that most white wines are fermented from the juice alone, drawn off from the grapes immediately after crushing. Because of this, white wines have practically none of the astringency red wines get from the tannins of the grape skins and seeds. The fermentation is usually conducted at a lower temperature than for red wines, since the white wines are more delicate and more easily injured by heat. The white wine usually clarifies more quickly and can be bottled earlier.

In California, a wide variety of grapes is used for white table wines. Some of the principal ones are Semillon, Burger, Palomino, green Hungarian, Sauvignon Vert, Sauvignon Blanc, Riesling, Chasselas, Folle Blanche, and numerous others. In the East, white table wines are made from the juice of the Niagara, Elvira, Delaware, Concord, Iona, Diana, Isabella, Catawba, and the light cold-pressed juice of some black grapes.

(b) Types

The general types of table wine are illustrated by the following list of common table wine designations, grape varietal names being marked with an asterisk:

1. **Red Table Wines:** *Claret*, Cabernet*, Carignane*, Concord*, Grignolino*, Mourastel*, Norton*, Zinfandel*; *Burgundy*, Charbono*, Durif*, Gamay*, Ives*, Petite Sirah*, Pinot Noir*; *Chianti*, Barbera*, Barberone.

2. **White Table Wines:** *Rhine Wine* (syn. *Hock*), Moselle, Delaware*, Elvira*, Folle Blanche*, Gutedel*, Riesling*, (including the Johannisberger (or White) Riesling, the Sylvaner or Franken Riesling*, and the Grey Riesling), Traminer*, Ugni Blanc*; *Sauterne* (including Dry Sauterne, Sweet (or Haut) Sauterne, and the "Chateau" or very sweet Sauterne), Catawba*, Golden Chasselas* Sauvignon Blanc*, Semillon*; *Chablis* or *White Burgundy*, Chardonnay*, Pinot Blanc*, Muscat*, Malvasia Bianca*, Moscato Canelli* (or Muscat Frontignan*); *White Chianti*.

5. Production of Dessert Wines

We have seen that table wines are the types predominating in the cooler grape-growing areas where the fruit is naturally suited to a dry, or moderately sweet, naturally fermented wine of about 11–14% alcohol by volume, eminently useful for meal-time consumption. Dessert wines, on the other hand, have developed their several types primarily in the warmer grape-growing regions, where the relatively high sugar content (24° Balling or more) renders the grapes less suitable for table wine; and their

special use has been primarily before, or after, rather than with, the meal, or as an occasional wine. Commercial production of dessert wines in modern times probably dates from the establishment of the port and sherry trades with England in the early 18th century.

As an occasional wine, a dessert wine has two characteristics that especially distinguish it from a table wine. The first is its taste, which involves either a special sweetness or a flavor supplementary to that of the grape, or both. The second is its nonperishable character, which is furnished by the slightly extra alcoholic content, usually varying from 17 to 21% by volume.

(a) *Commercial Production*

To insure the desired sweetness and nonperishable character, dessert wine production fundamentally involves wine spirits (added) and unfermented residual sugar. The wine spirits are, in fact, brandy distilled from grape wine, usually, though not necessarily, at a proof somewhat higher ($170\text{--}188^{\circ}$) than that employed for the commercial, or drinking, brandy ($140\text{--}165^{\circ}$), and with resulting lighter body. The unfermented residual sugar content may be that of the original juice left unfermented as a result of adding wine spirits during the fermentation, or from adding condensed or uncondensed grape juice to the wine before, during, or after fermentation. The actual practice varies widely in different districts and sometimes all methods are combined. The federal standards of identity prescribe a minimum alcohol of 17% by volume for sherry and of 18% by volume for the other predominant dessert wine types, these conforming to the general commercial practice, in which the actual range is about 20% by volume.

(b) *Types*

While dessert wine production methods for the various types do not differ much basically, yet selecting the grape, coupled with some marked variations in treatment, has resulted in the following groups of types: the sweet muscat dessert wines, usually white (amber), sometimes reddish, principally muscat; sweet red dessert wines from nonmuscat varieties, principally port; sweet white dessert wines from nonmuscat varieties, principally angelica and white port; slightly to fairly sweet, amber (originally white), rancio-flavored dessert wines from nonmuscat varieties, principally sherry, but including the similar types Madeira and Marsala; dessert wines flavored with aromatics—the aperitif wine group, including vermouth (based on white dessert wine) and the quinined dessert wines (usually based on red dessert wine). The aperitif wines and the drier wine rancio-flavored sherries are often grouped together as appetizer wines because of their suitability for use with appetizers and immediately preceding the meal.

Muscatel.—The muscat grape is found in the cool regions (e. g., Alsace, Piedmont) but achieves prominence in the warmer areas for dessert wines. In Europe, it is especially prominent in the Mediterranean area; in the United States, it is grown

chiefly in the warm, dry interior portions of California, particularly in the Fresno-San Joaquin district. The muscat comprises many subvarieties: when unqualified, the Muscat of Alexandria is implied, the other subvarieties usually being specifically indicated, *e. g.*, Muscat Frontignan (also known as Muscat Canelli). Certain subvarieties are dark skinned (*e. g.*, Muscat St. Laurent, Muscat Hamburg, and the related variety Aleatico), and from these sweet reddish dessert wines may be made. Muscatels are usually sweet, ranging from 10 to 15% in unfermented residual sugar content. The fruity characteristic muscat flavor marks unmistakably all wines of this group.

Port.—This type became highly developed commercially as a result of the favorable treaty of Methuen (1713) between England and Portugal; and, through the British wine merchants, these wines, grown in the upper Douro river valley and blended and aged at the seacoast city of Oporto, have found their way all over the world in the succeeding two centuries. Similar wines grown elsewhere are generally similarly designated. The type is found well established in southern France, South Africa, and the United States. Port is a rich, heavy-bodied sweet wine, deep red in color, with a residual sugar content usually from 9 to 14% (usually natural grape sugar). There is a lighter-colored, lighter-bodied port called tawny port, usually made from grapes that are not as rich in color as those used for the normal port.

Angelica and white port are sweet, white dessert wines usually highest in residual sugar content, which is often 15% and sometimes higher. White port is straw colored and derives its name from wines of this type grown to some extent in the Douro valley. Angelica, resembling white port, is a name originating in California; it is mild and fruity, and ranges in color from straw to amber.

Sherry.—The present Spanish regulations officially designate the origin of sherry as "Jerez-Xeres-Sherry," thus indicating the international development of this trade, like that of port, through the English wine merchants. The Marsala wine from Sicily was also an English 18th century development. On the other hand, Madeira was popularized in, and brought to, the United States under American canvas.

These white dessert wines are particularly characterized by their "rancio" or "nutty" flavor, which is obtained, wherever this type of wine is made, by the combination for a period during aging of oxygen and warmth; also, principally in the case of the Jerez sherries, by the peculiar characteristics of the Jerez wine yeast which, after an alcoholic content of about 15% by volume is obtained (by fermentation plus any necessary addition of wine spirits), induces over the surface of the wine formation of a film which is allowed to remain for a further period during storage. This film yeast is believed to be responsible for a special flavor distinguishable from the ordinary rancio flavor; but it is also indicated that it was not generally used in the district of Jerez de la Frontera (near Cadiz, and whence sherry derived its name) until the middle of the 19th century. Experimental use of the Jerez yeast elsewhere (*e. g.*, California) indicates the possibility of its employment on a commercial scale in other wine-growing districts.

Sherries, and the similar Madeira and Marsala types, are usually made in the same

manner as other white dessert wines, the sugar content being somewhat less (dry sherry, up to 2½%; medium sherry, 2½ to 4%; sweet, cream, or golden sherry, 4 to 7% or slightly higher), and with the additional factor of temporary storage in warmth with exposure to oxygen (e. g., 3 months at 140° F., although actual practice varies widely and the heat may be obtained by heating the storage casks or by placing the casks in the open exposed to the sun). In the Jerez district, after exposure and completion of contact with the film developed by the yeast, the wines are graded (*finos* are quite dry, *olorosos* fairly sweet) and aged and blended under the *solera* system with wines of previous years of the same character. *Amontillados* and *vino de pastos* are developments of the *fino* type; *amorosos* and *golden* or *East India* sherries of the *oloroso* type. In the drier sherries, the rancio or film yeast flavor is relatively more highly developed, and the wine lends itself readily to appetizer use.

In the United States, many varieties of grapes are used for sherry wine, although the Palomino grape is considered the best for California sherries. The wine intended for sherry is usually aged at warmer temperatures than other wines. In California it is usually "baked" at temperatures from 100 to 140° F. or over for several months to a year or more in heated rooms, cellars, sometimes in kilnlike structures with fire heat, in tanks with heating coils, and sometimes by exposure to the sun.

In other wine regions, principally in New York State, the chief methods are prolonged exposure of the barrels to the sun and weather, the use of warm coils rarely over 120° F., and the use of pure oxygen or air accompanied by much pumping and circulation.

6. Production of Sparkling Wines

Sparkling wines are table wines which have been made effervescent by fermentation within closed containers. The most important member of this class is champagne; the next in importance in quantity is sparkling Burgundy, which is made to a much smaller extent. Other sparkling wines are sparkling Moselle, sparkling sauterne, sparkling muscat, and other sparkling fruit wines.

The process of making bottle-fermented champagne is as follows: The selected wine, usually a blend of several white wines produced from the juice of white grapes and in some instances the white fermented juice of some black grapes, is pumped into a special mixing tank. To this quite dry wine are added 2 to 2½% by weight of sugar and a fermenting must containing a culture of champagne yeast. This yeast is a special granular variety developed to ferment the sugar added in a medium of 11 to 12% alcohol by volume, and to function under the pressure of 8 or 9 atmospheres which may develop in the bottles. The wine, with its added sugar and yeast, is kept in constant agitation in order to maintain its uniformity as it is being bottled into new champagne bottles. The bottles are stoppered with a "tirage" cork fastened in place by a strong steel "agraffe," and stacked resting on their sides in deep rows. Fermentation goes on in the bottles; and although it may be complete at the end of a month, the bottles are seldom touched until over three months have elapsed. The champagne

wine is now in its safest and most important stage of manufacture and may be left in the stacks several years or until the wine maker chooses to rack down the sediment, disgorgé, and permanently stopper it. The secondary fermentation in the bottle leaves a sediment of yeast, fine particles of grape material, and tartrates. During the process of racking this sediment is worked into the neck of the bottle against the stopper: the technique involves placing the bottles on end in special racks at low temperature and periodically giving them a right and left twirling motion.

The tirage wine after fermentation and racking and still bound by the steel agraffe usually has a pressure of 90 to 100 lbs. per sq. in. (5 to 6 atmospheres) and is then ready for disgorging. This process consists of freezing the wine in the neck of the bottle (still held upside down) in brine to which glycerol may be added and which is cooled to 5-6° below the freezing point of water. The agraffe is carefully removed. The bottle, now upright, blows out the tirage cork along with a frozen pellet of wine containing the sediment. About the same amount of liquid is expelled from each bottle. An exact amount of "dosage," a combination of wine, brandy, and sugar, is added from a buret-like bottle. Also added is any champagne needed to bring the bottle up to the proper volume. A large, long, somewhat rectangular champagne cork is squeezed to about one-half its volume by four sliding jaws of a compressing device attached to the machine, and a plunger drives the cork partly into the bottle. Another machine rounds out the top of the cork in a mushroom form and puts on the small metal cap and the wire fastenings, but does not drive this permanent champagne cork any farther into the bottle.

The grapes used in California for champagne are the same as those used for the best California dry white wines. In the upper New York State area, where most of the eastern champagne is made, a blend of wine is selected which is usually produced from Catawba, Delaware, Elvira, Dutchess, Isabella, and Iona grapes. Also in the blend may be white wine produced from the white juice of certain black grapes such as the Concord and other varieties of near-by black grapes. In France, the principal grapes used for champagne are the black and white Pinot. The same kind and quality of still wine with all the usual preliminary cellar treatment that is used for wine intended for bottle fermented champagne also usually form the basic wine used for bulk process champagne and carbonated wines as well.

In the production of champagne by the bulk or Charmat process, wine is further fermented in large glass-lined tanks instead of bottles, the capacity of the tanks ranging from 50 to 1000 gallons. The same types of wine yeast and sugar solution are employed as for the bottle process. Fermentation is allowed to continue for 3 or 4 weeks, during which time the pressure reaches 100 lbs. or more per sq. in. As soon as the pressure reaches the point desired, cooling the wine to 20-25° F. stops fermentation. The champagne is kept at this temperature for a week or more, during which time the yeast, wine lees, and tartrates settle to the bottom of the tank. The wine is then filtered under the same pressure through thick filter devices from the original tank in which fermentation took place into another tank, and then into the bottle, without any appreciable loss of pressure. The dosage used for bulk champagne is of about the same

character as is used for bottle-fermented champagne, and may be added to the wine in the pressure tanks or to the empty, pressure-tested champagne bottles before the finished bulk champagne is filled in. The process for corking, capping, mushrooming, and wiring the cork is the same as described for bottle-fermented champagne.

Artificially carbonated wines are produced by adding the desired amount of sweetening, cooling the wine nearly to freezing, and introducing carbon dioxide in a fine stream while the wine is agitated. The carbonated wine is stoppered with champagne corks and finished in the same manner as for champagne.

7. Production of Vermouth

At one time, all French vermouth and all Italian vermouth were produced in these countries of origin only, from certain traditional herbs and aromatics growing in the mountainous or alpine regions of these respective countries. During the many years of production in Italy and France, these wines became uniform in character and were exported to all parts of the world and to the United States, to the extent of between one to two million gallons annually. During the second World War, the original sources were entirely shut off. However, Argentina and, to a much smaller extent, other South American countries began to increase extensively the exportation of both types of products. In 1940, a typical importing year, about 880,000 gal. of vermouth came from Italy, about 450,000 gal. from France, and about 86,000 gal. from Argentina. About two-thirds of the vermouth imported in normal times is sweet vermouth, and about one-third dry.

In the United States, before the Prohibition era, only a very small amount of vermouth was produced; but since repeal, it has been produced in steadily increasing amounts. In 1943, vermouth production in the United States was at its greatest height and constituted by far one of the fastest growing wine items. For the fiscal year of 1942 (July 1, 1941, to June 30, 1942), in the United States, there were produced in bonded wineries 1,921,514 wine gal. of vermouth, and at rectifying plants, 5169 proof gal. (about 15,200 wine gal.). In 1943, almost all the American-made vermouth was made by bonded wineries. It is required that vermouth be made with dessert wines, and in a separate room or department which does not communicate with any other part of the winery.³ If a bonded winery or a rectifying establishment decides to produce vermouth, it must file a formula listing all the ingredients to be used and the method of manufacture. Besides vermouth, rectifiers produce, in a relatively small extent and usually with a red wine base, certain aperitif wines which are lighter in herbs and aromatics, and which are intended to be used as wines and usually are consumed as such. These usually bear proprietary names. At present, the quantities produced are of no significance commercially.

Vermouth is a sweet dessert wine to which has been added a selected mixture of aromatic and bitter herbs, either in the crude dry form, as infusions, or as extracts produced from herb combinations.

³ Sec. 2801 (e) (4), Internal Revenue Code, and U. S. Treasury Department, Bureau of Internal Revenue, Regulations No. 7, Pars. 86, 86 (a), 87, as amended by Treasury Decision 4844.

At the present time, the herbs used for the domestic production of vermouth are obtained from previously imported stocks, from certain Latin-American countries, and from herbs grown in the United States. The herbs generally used to flavor vermouth may include angelica, cinchona, blessed thistle, spices, elder, gentian, coriander, wormwood, centaury, orange peel, thyme, angostura, quassia, marjoram, and numerous others. Some of the same herbs often are used for both vermouth types.

The herbs and the wine base used in France and Italy are somewhat traditional and do not vary to any noticeable extent; consequently, the products are characteristic. In the United States, a slightly wider range of ingredients has been used in the production of the two well-known vermouth types, the sweet or Italian type, and the dry or French type. The sweet vermouth will range in alcoholic content from 15 to 17% by volume and will contain 12 to 20% by weight of total sugar; the color will vary from a medium brown to a dark brown color; and the wine base will usually be a wine of the muscat or angelica type. Caramel coloring may be added to adjust the vermouth to a definite or uniform shade. Dry vermouth will range from 18 to 20% alcohol by volume and contain from 3 to 5% by weight of total sugar; the color will vary from a pale amber or golden to a slightly darker golden brown; and the wine base will more often be a light-colored, fairly dry sherry. In California, a white wine of the sauterne type is sometimes used as a base for French-type vermouth.

The principal current use of vermouth in the United States is as an ingredient in mixed drinks. The sweet vermouth is an important part of the Manhattan cocktail and the dry is an important ingredient in dry Martini cocktail. Vermouth is used in the same manner as wine to a small, but increasing, extent in the United States, and to a considerable extent in the countries of their origin.

8. Production of Fruit and Berry Wines

Besides grape wines, a large amount of other wines are manufactured. Next in quantity to grape wine is blackberry wine (sometimes apple wines). Wines are also made from peaches, loganberries, elderberries, strawberries, raspberries, and other fruits and berries.

The production of these wines may be as simple as adding sugar to the crushed fruit or juice, fermenting the mass with or without the addition of a yeast culture, filtering or straining the liquid, and storing for use as wine.

The usual commercial way, however, is to add enough dry sugar to the whole crushed mass of fruit or to the juice to produce in the wine, after fermentation, from 12 to 13% alcohol by volume. If the acid of the must is in excess of 5 parts per thousand, a sugar and water solution may be added in quantity sufficient to reduce the acid to 5 parts per thousand; in no case should the volume of the resulting product be increased more than 35%. If the acid of the must is over 7.6 parts per thousand, 35% sugar and water solution may be added. Numerically this is 538.4 gal. sugar water per 1000 gal. must. The pulp is usually fermented along with the juice. At the end of fermentation the wine is drawn from the pulp, filtered, stored, racked, and refiltered, and

perhaps sweetened with not over 11% by weight of dry sugar. This wine may be pasteurized or have added to it wine spirits from the same kind of fruit or wine.

The amount of natural acids in berries like blackberries, strawberries, loganberries, and elderberries is comparatively high, ranging from about 1% to over 2%. In apples, peaches, cherries, plums, and other fruits, the natural acid content is lower than that of berries. Most fruits and berries have low sugar contents; and the quantity of the dry sugar to be added is based on the volume of the juice and its natural sugar content. The extent of amelioration (addition of sugar and water) is based on the natural acid content of the fruit. See Table 65, pages 740 and 741.

The production of fruit wines and berry wines is more difficult, and requires more technical control, than the production of ordinary grape wines. Prospective fruit and berry wine producers should study carefully Internal Revenue Regulations No. 7 (relating to the production of wines) and No. 4 (relating to the labeling and advertising of wine under the provisions of the Federal Alcohol Administration Act, as amended), as well as Circular A. T. U. 621, Circular 568, and Circular 686.

Cider

Apple wine and hard cider are synonymous. What is generally called cider is apple juice or sweet cider. The consumption of this latter beverage exceeds that of any other fruit juice.

Section 330 of the Liquor Tax Administration Act, approved June 26, 1936 (Section 3045 of the Internal Revenue Code), defines apple wine as the product of the normal alcoholic fermentation of the juice of sound ripe apples with or without the addition of sugar. Section 611 and Section 613 of the Revenue Act of 1918, as amended (Section 3030 of the Internal Revenue Code), levy a tax upon all still wines, artificially carbonated wines, and sparkling wines.

Under a literal interpretation of the wording of the above section of the law, all fermented apple juice produced with or without the addition of sugar and having an alcoholic content of $\frac{1}{2}$ of 1% or more is subject to the wine tax. In view of the widespread manufacture of cider in rural communities and its sale at roadside stands and groceries, it has not been customary to tax the distinctive farm product known and sold as cider.

The product resulting from the normal alcoholic fermentation of apple juice only is not deemed to be wine if it is made and sold as plain cider. However, if any material, except sugar for sweetening purposes after complete fermentation, is added which will alter the nature of this product, it is no longer considered cider and is subject to taxation.

The carbonation of cider materially alters the character and composition of the product, and changes it from a plain farm product to an alcoholic beverage which is sold commercially in competition with taxed beer and carbonated wine. If naturally carbonated fermented apple juice is made on bonded winery premises, it is subject to the sparkling wine tax of 15 cents on each half-pint or fraction thereof. If the product is artificially carbonated, it is taxed at 10 cents on each half-pint or fraction thereof.

Naturally fermented cider may be tax-paid as still wine, and received at a rectifying plant for artificial carbonation subject to the payment of a rectification tax of 30 cents per proof gallon and the tax on artificially carbonated wine of 10 cents on each half-pint or fraction thereof.

Cider (apple wine) is prepared by fermenting apple juice and pulp, which ferment readily without added yeast. The alcoholic content of naturally fermented apple juice may reach 8% by volume. In some instances, when the sugar content is unusually high and concentrated because the apples have lost a great deal of moisture in storage, the alcoholic content may be higher. Generally, the average alcoholic content of naturally fermented apple juice or crushed apples is nearer 5.5%. When apple cider is fermented with sugar added in a bonded winery, the product is taxable, and is known as apple wine. There are two kinds, one containing not over 14% alcohol by volume, and the other made with apple spirits up to 21% by volume. If the wine becomes effervescent by natural means, in the bottle, or in a closed tank, it is classed as sparkling wine and is taxable as such. Modern filtering equipment using purified diatomaceous earth, kieselguhr, and other filter aids yield a very clear product.

III. CORDIALS (LIQUEURS)

The terms "cordial" and "liqueur" should be considered synonymous because the names have been so loosely used for so many years that no real boundary can be drawn between them. Originally, most cordials were imported from France and Holland, smaller amounts from other European countries, and practically none from elsewhere. Since repeal, some of these products have been made in the United States. With the curtailment of imports by the second World War, the manufacture of cordials in the United States has been greatly stimulated.

Cordials and liqueurs are obtained by mixing or redistilling neutral spirits, brandy, gin, or other distilled spirits with or over fruits, flowers, plants, or the pure juices of these products, or other natural flavoring materials, or with extracts derived from infusions, percolation, or maceration of such material, to which ordinary granulated sugar, dextrose, or both have been added in an amount not less than 2 $\frac{1}{2}$ % by weight of the finished product. Synthetic or imitation flavoring materials may not be included. The mixing of these spirits, sugar, flavoring extracts, juices, herbs, etc., must be performed by a cordial rectifier. No matter where this class of merchandise is produced in the United States, its maker must qualify as a rectifier and must pay a tax of 30 cents on each proof gallon. The rectifier takes the spirits in whatever form he deems necessary and gives it an entirely different character. For instance, sloe gin, rock and rye, crème de menthe, and a large number of concoctions are manufactured which are all different from the spirits used as a base. The number of rectifiers in the United States in 1934 was more than 500; each year, however, the number decreased until, in July, 1942, there were less than half this number of legally qualified rectifiers.

Cordials (or liqueurs) must not be designated as distilled or compounded, although the principal difference between cordials and true wines and distilled spirits is that

the former are compounded. Cordials may be placed in three categories. The first class of cordials is made by macerating the herbs, fruits, and other ingredients in alcohol, and distilling; the distillate is sweetened and colored. The second class of cordials is made by infusion or maceration, sweetening, and filtering. The third class is made with the addition of a natural or synthetic fruit, flower, or herb oil to the spirits, along with sugar and coloring matter.

The types of cordials produced are unlimited because of the large number of vegetable, fruit, flower, and herb flavors and their combinations, and the various synthetic and imitation flavors that may be employed. Cordials, because of their heavy sweetness, are rarely consumed in any quantity and are usually served as a dessert or after-dinner confection, or in mixed drinks and cocktails.

The cordial producer's equipment consists of storage tanks for spirits, the apparatus necessary for percolation, distilling, mixing, filtering, and, in some few instances, for storing or aging.

A few of the best known cordials are:

Absinthe	Crème de Cacao, Cof-	Rock and Rye	Sloe Gin
Anisette	fee, Menthe, and	Forbidden Fruit	Schrank Kyszm
Angelica	Yvette and a large	Goldwasser	Blackberry Cordial
Benedictine	number of other	Grenadine	Ojen
Cassis	crèmes	Triple Sec	Maraschino, and many
Celery	Cointreau	Kümmel	fruit-flavored sweet-
Chartreuse	Cherry Heering	Strega	ened brandies

IV. DISTILLED LIQUORS

Because of the many unrelated and conflicting reports, no agreement among authorities exists as to the exact origin of any of the distilled spirits or as to whether whisky, brandy, rum, or alcohol was the first distilled beverage to appear and be recognized as such. It is well known, however, that the industry is centuries old; many of the early crude processes, methods, theories, and superstitions have been steadily but slowly replaced by more definite, scientific, and efficient modern processes. Through the efforts of federal and State officials, spirit technologists, and the cooperation of the industry, distilled spirit groups are now uniformly classified. For tax purposes, alcoholic beverages containing upward of 24% by volume are technically classed as distilled spirits.

According to information from the United States Treasury Department, production at registered distilleries increased from 143,455,192 tax gal. during the fiscal year of 1940 to 175,208,746 during the fiscal year of 1941. Since the repeal of Prohibition, the peak production was 258,956,886 tax gal. during the fiscal year of 1937. The 1941 production consisted of 121,851,983 gal. of whisky; 2,614,946 of rum; 5,177,357 of gin; 25,363,877 of brandy; and 20,200,583 of other spirits. Forty-seven per cent of the whisky just noted was produced in Kentucky and 19% in Illinois. Most of the brandy was produced in California. The remaining production was widely distributed. In

the order of their commercial importance the respective classes are: neutral spirits, whisky, gin, brandy, rum, and several minor groups.

The sources of distilled spirits are legion, as distilled spirits may be made from anything fermentable—saps, sirups, juices, grasses, vegetation, fruits, berries, nuts, or vegetables. The sources of ordinary commercial production are molasses, cereal grains, grapes, and other fruits.

Alcohol, or neutral spirits, is made principally from molasses and, in smaller amounts, from corn and other grain. Whisky is produced by fermentation and distillation of grain, principally corn and rye. Brandy is made from fruit mashes, and wine is made chiefly from grapes, but also from apples and other fruits and berries. Rum is derived principally from molasses and in smaller quantities from cane juices. Distilled gin is obtained by distilling diluted neutral spirits over or with aromatics, principally juniper berries. Compound gin is made by adding aromatics, oils, and other permitted ingredients directly to neutral spirits. The alcoholic distillates from a fermented cereal mash and fermented molasses or cane products mash are classed as whisky or rum, respectively, as long as they retain the characteristics generally attributed to them. When the proof of distillation is 190° or over (with sufficient rectification), the distillates lose the characteristics by which we may recognize their source and are rather neutral and like pure ethyl alcohol in character. It is quite difficult, if not impossible, to distinguish between commercial neutral spirits produced from grain and that produced from sugar-cane products.

1. Neutral Spirits

Alcohol, or neutral spirits, is distilled from any material at or above 190° proof whether or not such proof is subsequently reduced. It is the purest alcoholic product that can be made by ordinary distillation. Its only odor and flavor are those characteristic of alcohol, so that if neutral spirits are used to fortify a beverage no additional flavor is imparted. There are five common grades of alcohol and neutral spirits:

- (a) Spirit quality 190°.
- (b) Alcohol quality 190°.
- (c) Denaturing quality 188-190°.
- (d) C. P. quality 96%—192° proof.
- (e) Absolute alcohol, U. S. P. or A. C. S.

Two sets of specifications for alcohol, those of the U. S. P. and those of the A. C. S., are applicable to alcohol. The latter are the more rigid. As a rule, ordinary commercial alcohol (95%) meets both specifications. The most objectionable impurities are aldehydes and fusel oil, both of which impart characteristic odors and may be detected by standard tests.^{4,5}

⁴ United States Pharmacopoeia, XI, 1936, p. 45.

⁵ Ind. Eng. Chem., 20, 980 (1928).

2. Commercial Ethyl Alcohol

Ethyl alcohol may be produced from four classes of raw materials: (1) Saccharine materials (sugar beets, sugar cane, blackstrap molasses, high-test molasses, fruits, fruit juices). (2) Starchy materials (corn, wheat, oats, barley, Irish potatoes, sweet potatoes). (3) Cellulose materials (waste wood, sawdust, sulfite liquor from paper pulp mills). (4) Gases such as ethylene, acetylene, carbon monoxide (found in natural gas, coal gas, and waste gases from certain industrial processes or specially prepared for the manufacture of alcohol, as, for example, the production of ethylene by cracking petroleum oil).

For many years prior to the second World War, the greater part of commercial alcohol was produced in the United States from blackstrap molasses and high-test molasses imported from Cuba, supplemented by relatively small quantities of Puerto Rico and domestic molasses. Blackstrap molasses, which is a by-product in the manufacture of sugar, contains from 50 to 60% sugar. Approximately 2.5 gal. of such molasses will produce a wine gal. of anhydrous or absolute alcohol, being approximately 90% of the theoretical yield. In recent years, because of the overproduction of sugar, many millions of gallons of high-test molasses were produced in Cuba by concentrating raw cane juice with no recovery of crystallized sugar. The concentrated cane juice or high-test molasses contains approximately 75% total sugar. Under normal conditions, molasses is one of the cheapest and most convenient materials for producing commercial ethyl alcohol. No processing is necessary except sterilization and dilution with water to the proper strength for fermentation (approximately 16 to 24 Balling). Yeast is then added to the diluted molasses in the form of a yeast mash, and fermentation is generally completed in approximately 48 hours. The fermented mash or beer containing 8 to 12% alcohol is then distilled in distilling equipment capable of producing 95% alcohol.

Most of the industrial alcohol plants are located on the lower Mississippi River or Atlantic Seaboard where molasses is received in tankers and in some cases pumped directly into fermenters for sterilization and dilution to the proper gravity for fermentation. During the fiscal year ending June 30, 1941, over 70% of the alcohol produced in this country was made from molasses.

Small quantities of commercial alcohol are made from grapes and pineapple refuse material from canneries in Hawaii.

Starchy materials, such as grains and potatoes, require more processing than molasses for the production of alcohol. The grains or potatoes must be ground or cut up and then cooked under pressure with water. After the grain or potato mash has been thoroughly cooked, it is necessary to convert the starchy material into fermentable sugars by addition of acids or barley malt. When the starch material has been converted into sugars, principally maltose, it is pumped into fermenters and then fermented by adding yeast in the usual manner. After 48 to 72 hours, the mash has been completely fermented, and is distilled in the same kind of distilling equipment used for the distilling of alcohol from fermented molasses. Approximately 2.5 gal.

of absolute alcohol or 5 gal. of 100-proof alcohol can be obtained from a bushel of corn. Higher yields can be obtained from No. 1 grain processed in the proper manner.

Alcohol produced from grain costs more than alcohol produced from molasses because of the initial cost of the raw material and the additional treatment or processing necessary to convert the starch into sugar so that it can be fermented. Most of the industrial alcohol plants or distilleries producing alcohol from grain are located in the Corn Belt. During the fiscal year ending June 30, 1941, approximately 6% of the alcohol was produced from grain. The cost of producing alcohol from corn and wheat can be, and is substantially, reduced by salvaging the slop from the stills after the alcohol has been removed. The slop is dried and the unfermentable residues in the grain are available as stock feed. In some cases, the untreated slop is fed to cattle at or adjacent to the distillery.

Potatoes were never used in the United States as a raw material for the production of alcohol until recently, but experimental plants are now operating which use Irish and sweet potatoes. Because of the shortage of corn and the inability to import molasses from Cuba, millions of bushels of wheat during 1943 were used in the production of alcohol, and some of the plants formerly using molasses were converted to grain plants.

For economic reasons, cellulose materials have never been extensively employed for the production of alcohol in this country. Where waste wood or sawdust is used, the cellulose is converted by hydrolysis with acid to sugars and the sugars then fermented to alcohol by yeast in the usual manner. Waste sulfite liquors from paper pulp mills contain from 2-4% sugars, approximately two-thirds of these sugars being fermentable. Before sulfite liquors can be fermented, it is necessary to neutralize the various acids present in the liquor. Under normal conditions, it has not been profitable to use these waste liquors as a source of alcohol because of the tremendous volume of liquor that must be processed in order to obtain any volume of alcohol. Considerable progress is being made at the present time in recovery of by-products which, with the present high price of alcohol, will probably make it feasible to use sulfite liquors as a source of alcohol in the Northwest, where millions of gallons are available and are a problem with respect to their disposal.

Ethylene gas, produced by cracking petroleum, is being used extensively for the production of alcohol. Under normal conditions, it is probably the cheapest source of material. During the fiscal year ending June 30, 1941, over 23% of alcohol produced was manufactured from ethylene. The chemical reaction for converting ethylene into ethyl alcohol is very simple, but in actual practice expensive equipment and extreme care and supervision must be used in obtaining satisfactory results. The reactions involved are illustrated by the following equations:



The ethylene gas is passed into sulfuric acid of a certain concentration at certain temperatures with the formation of ethylsulfuric acid or ethyl sulfate. This material is

then treated with water and, by hydrolysis, ethyl alcohol and sulfuric acid are formed. The ethyl alcohol is separated from the acid by distillation and then purified. The diluted sulfuric acid is then concentrated to the proper strength and re-used for the production of more ethylsulfuric acid. As previously stated, the process must be rigidly controlled or large quantities of ether, ethereal oils, and other by-products are formed, with a resulting low yield of ethyl alcohol.

TABLE 67
PRODUCTION OF ETHYL ALCOHOL IN 1941

Kind of material	Quantity used		Alcohol produced	
	Amount	Unit	Proof gallons	Per cent of total
Molasses ^a	220,898,526	Gallons	210,426,805	70.41
Ethyl sulfate	53,399,664	Gallons	69,902,800	23.39
Grain ^a	199,119,727	Pounds	17,532,441	5.87
Pineapple juice	1,831,381	Gallons	227,326	0.08
Cellulose pulp, chemical, and crude alcohols mixture:				
Crude alcohols mixture	2,365,256	Gallons		
Cellulose pulp and chemical mixture	15,365,950	Pounds	575,730	0.19
Other mixtures:				
Molasses	921,866	Gallons		
Corn sugar by-product	2,245,793	Pounds		
Malt	1,265,953	Pounds		
Corn	1,110,284	Pounds	180,315 ^b	0.06
Potatoes	686,585	Pounds		
Barley	8,758	Pounds		
Bran	5,894	Pounds		
			298,845,417	100.00

^a Additional amounts used in combination with other materials included under "other mixtures."

^b Includes 1045 proof gallons produced at an experimental plant from materials not shown.

The distilling apparatus for commercial ethyl alcohol from molasses consists of beer feed tank, heat exchanger, beer heater, beer still, dephlegmators, condensers, rectifying columns, fusel oil separators, aldehyde stills, and other minor devices. After the distilling operations are completed, the alcohol is pumped to receiving tanks, from which it is transferred through Government-supervised weighing tanks to bonded storage. The fermented mash from corn or other grain is distilled in the same manner.

3. Whisky (Domestic)

American whisky as made in the United States, and to some extent in Canada, differs sufficiently from that made in Scotland and Ireland so that the type may be said to have originated in this country, although it is certain that the name "whisky" came from abroad. The original stills were copper, handmade pots with goosenecks and condensing worms. This was followed by the 3-chambered beer still and its modifications, and still later by the continuous column still. The latter, while capable of being adjusted to produce a continuous distillate lower than 160° proof, generally is

used to produce a product greater than 160°; when necessary, it can be used to produce neutral spirits.

The use of the continuous still can be attributed to the influx of English and Canadian capital and personnel, who were in favor of a much lighter "bodied" whisky than the original American type, which was not easily obtainable from the pot or the 3-chambered beer still. A small amount of this very light-bodied whisky is distilled in one operation at above 160° proof in continuous stills. American tastes for light-bodied whisky seem to have been met successfully by blending straight rye and bourbon whisky with neutral spirits distilled from corn.

The early colonists in Maryland and Pennsylvania raised rye as the principal grain crop, so that rye grain was the first material to be used for whisky in America, with barley malt employed for the conversion of starch. A great deal of resentment against the original tax levied on this rye whisky resulted in the so-called Whisky Rebellion. Some of these distillers and growers migrated to Kentucky and Indiana, set up stills, and used corn instead of rye because corn, at that time, was one of the principal agricultural crops in those States. Bourbon whisky obtained its name from the county in which corn whisky was first distilled. Bourbon whisky has proved to be more generally popular than rye whisky.

There is about ten times as much whisky produced and sold in the United States as all the other distilled beverage liquors combined. This includes all gin, rum, and beverage brandy. Over 121,851,983 gal. of whisky were produced in fiscal year 1941, and 120,257,421 gal. in fiscal year 1942. The stocks of whisky in bonded warehouses being stored and aged in 1942 were over one-half billion tax gal. Approximately 90% of all the beverage-distilled spirits sold is whisky. Gin comprises about 8% of the total volume, and rum about 1%. About 4% of the whisky sold is Scotch.

(a) *Manufacture*

The usual process of making whisky is as follows: The grain is carefully inspected, cleaned of dust and foreign materials, and ground into a coarse meal of a standard grind. It is then mashed into boiling water and cooked, often under pressure, until the starch granules are loosened and completely ruptured. The mash is then cooled to the optimum malting temperature and about 10% malt is doughed in to convert the starches into sugars. This sweet mash is cooled to the best temperature for the introduction of yeast (usually a selected pure culture) and the mash is fermented into a "distillery" beer. Most of the whisky made at the present time is "sweet mash whisky" by which is meant whisky for which yeast is used in the fermentation of the mash. By "sour mash whisky" is meant whisky produced from a mash the fermentation of which was started by the use of spent beer or slop and barm from tubs previously set and fermented. From this point the fermented mash goes to the various types of still mentioned, to be distilled into whisky or into neutral grain spirits. The whisky, after distillation, is adjusted to the proper proof with plain or distilled water and is placed in new charred or re-used charred barrels. Occasionally, new plain barrels or re-used

plain barrels are employed. The barrels are always made from white oak. These are placed in bonded warehouses to allow the whisky to age. After the desired period of aging, the whisky is reduced in proof, usually with distilled water, bottled, and packed for further storage or shipment.

(b) *Definitions*

To the average consumer, the number of kinds of whisky appears confusing; but under the regulations of the Federal Alcohol Administration Act they are clearly classified as follows:

Whisky is an alcoholic distillate from a fermented mash of grain, distilled at less than 190° proof, in such a manner that the distillate possesses the taste, aroma, and characteristics generally attributed to whisky.

Rye, bourbon, wheat, malt, rye malt, and corn are whiskies which have been distilled at not exceeding 160° proof from a mash containing not less than 51% of the grain which bears its name, and are called straight whiskies. The minimum age required in order to be classed as straight whisky is two years. If the whiskies listed above are less than two years old, the word "straight" must be omitted. The aging must be carried out in new, charred, white oak casks, except for corn whisky, which must be aged in plain, seasoned white oak barrels. The minimum proof for bottling whisky is 80°.

Spirit whisky is a mixture of less than 20% by volume but not less than 5% of straight whisky and neutral spirits. The resultant product must not be less than 80° proof.

Bottled-in-bond whisky is straight whisky which the distillery has been allowed to bottle without payment of the excise tax, and to keep in bond under the provisions of the Bottled in Bond Act of 1894, although the tax may be paid before bottling. When bottled before tax payment, the tax is paid when the whisky is removed. It must be aged in charred barrels in bond for not less than four nor more than eight years. It must be bottled at 100° proof and cannot consist of two or more different whiskies. All operations of storage, aging, and bottling are carried out under rigid supervision of the Alcohol Tax Unit of the Bureau of Internal Revenue. While all other bottled whiskies must bear a red strip stamp over the neck, bottled-in-bond whisky has a green strip stamp.

Since Repeal, the terms "light bodied" and "heavy bodied" have appeared in reference to whisky. Generally speaking, light-bodied whisky contains a relatively small quantity of congeneric substances, color, and extractive matter. The manner of distilling, the kind of container (casks), and the length of time of storage determine whether the finished product after being matured for several years will be of a light- or heavy-bodied nature. If most of the congeneric substances or by-products of fermentation are removed by distillation and rectification, and the whisky is stored in re-used, charred, or plain casks in unheated warehouses, the resultant product will be a light-bodied whisky. If a relatively large quantity of congeneric substances remain in the whisky and it is stored in new, charred casks in a heated warehouse, the product will be heavy bodied and will have more aroma and flavor than a light-bodied one. Usually, light whiskies are distilled at well over 160° proof, and heavy-bodied whiskies at well below 160° proof.

Blending straight whisky with neutral spirits, of course, tends to make them light in body. There are five types of blended whisky commonly produced:

- (a) Whisky—a blend, composed of at least 20% by volume of 100-proof straight whisky and whisky or neutral spirits.
- (b) Bourbon (or Rye)—a blend, composed of at least 51% by volume of 100-proof straight bourbon or rye whisky, as the case may be, and whisky or neutral spirits.
- (c) Blended Straight Whiskies—mixtures containing two or more straight whiskies of varying ages.
- (d) Blended Straight Bourbon (or Rye) Whiskies—mixtures containing two or more straight bourbon or straight rye whiskies, as the case may be, of varying ages.
- (e) Bourbon (Rye)—Blended Straight Whiskies—mixtures of not less than 51% by volume of straight bourbon or straight rye whiskies, as the case may be, and other straight whiskies.

See Regulations No. 5, Bureau of Internal Revenue, Alc. Tax Unit (1943).

On all the above-mentioned blends, a United States Internal Revenue rectification tax of 30 cents per proof gallon must be paid and the product must be blended on a duly qualified rectifier's premises. However, if all the straight whiskies that are to be blended are four years old or more, if the finished product is not less than 90° proof, and no coloring or flavoring or other foreign ingredients have been added, then no

TABLE 68
MINIMUM, AVERAGE, AND MAXIMUM DATA ON ALL WHISKY SAMPLES^a

Age, years	Range	Proof	G. per 100 liters (calc. to proof)						Color, $\frac{1}{2}$ -in. Cell
			Total Acids	Esters	Fusel Oil	Solids	Alde- hydes	Fur- fural ^b	
0.5	New ^c	100.0	5.3	13.7	78.7	2.9	2.4	0	..
	Av.	101.2	7.7	17.0	161.1	10.5	7.6	...	..
	Max.	102.6	9.6 ^d	21.5 ^d	230.7	20.1	20.8	...	..
1	Min.	100.0	31.7	18.2	87.0	61.6	3.9	0.6	4.4
	Av.	101.3	40.3	26.5	166.8	92.5	9.6	1.7	7.1
	Max.	102.9	52.4	32.8	244.3	121.9	22.7	2.2	9.9
1.5	Min.	100.5	38.5 ^e	21.9	92.0	89.8	4.3	0.6	6.3
	Av.	101.9	50.1	29.9	166.5	114.4	10.2	1.9	8.6
	Max.	103.3	53.4 ^e	35.3	245.4	135.1	20.5	2.2	12.2
2	Min.	100.7	44.7	22.4	96.7	98.4	4.7	0.8	7.2
	Av.	102.8	55.9	32.4	167.0	131.3	10.4	1.9	9.8
	Max.	104.0	62.8	38.2	240.4	160.7	21.8	2.2	13.6
2.5	Min.	101.2	48.2	25.2	97.6 ^d	113.7	4.6	0.8	7.7
	Av.	103.8	59.7	34.7	168.3	143.0	11.0	1.9	10.8
	Max.	105.3	65.6	38.7	232.1	166.7	24.5	2.2	14.5
3	Min.	101.9	51.4	28.3	96.6	125.0	4.6	0.8	8.6
	Av.	104.8	62.8	37.0	168.6	155.8	11.0	2.1	11.9
	Max.	106.1	72.6	43.1 ^d	237.7	183.1	22.7	2.4	15.6
3.5	Min.	102.4	54.1	28.5	98.4 ^d	129.8	4.6	0.8	9.4
	Av.	105.6	65.2	38.9	172.0	163.0	11.1	2.1	12.3
	Max.	107.3	73.6	43.9 ^e	249.8	197.9	22.6	2.7	15.7
4	Min.	102.8	58.9	29.1	95.6	132.5	5.2	0.8	9.8
	Av.	106.6	67.9	40.0	171.2	172.8	11.2	2.1	13.1
	Max.	109.0	74.8	46.2	241.3	207.4	22.1	2.9	16.1
	Min.	104	59.8 ^e	37.6	96.0	141.8	6.0	0.8	10.2
	Av.	107.7	70.6	45.0	178.5	178.7	11.6	2.2	14.1
	Max.	110.7	78.6	48.8 ^d	260.8	213.8	21.7	3.0	17.3

^a P. Valaer and W. H. Frazier, *Ind. Eng. Chem.*, 28, 92 (1936).

^b In the maximum furfural the quick-age samples and those from one distillery which seemed abnormal were omitted.

^c Does not include quick-aged samples.

^d Highest or lowest was omitted as being slightly abnormal, and the next highest was taken instead.

^e Highest and next highest were omitted as being slightly abnormal.

rectification tax is due. On the back label the exact proof, the amount, the age, and the type of ingredients must be stated.

In Table 68 will be seen the maximum, average, and minimum analyses of 22 barrels of straight whisky, some distilled from sweet and some from sour bourbon mash, and also some from sweet and from sour rye mash, in 3-chambered copper stills with

TABLE 69
ANALYTICAL CHARACTERISTICS OF WHISKY^a

Age, years	Value ^b	Proof	Total acidity	Fixed acidity	Esters	Alde- hydes	Fur- fural	Fusel oil	Solids	Color	Tan- nins	pH
A. Individual Barrels												
0	$\bar{L}U$	102.5	14.8	4.8	30.9	3.9	3.1	160	28.3	0.148	6	5.12
	\bar{X}	101.4	6.8	2.0	18.2	1.7	1.2	118	11.4	0.048	1	4.76
	$\bar{L}L$	100.8	0.0	0.0	5.5	0.0	0.0	76	0.0	0.000	0	4.40
1	$\bar{L}U$	103.4	71.0	17.4	40.5	6.8	3.2	166	159.1	0.405	52	4.43
	\bar{X}	102.1	56.9	10.8	26.8	4.0	1.7	124	123.1	0.305	27	4.29
	$\bar{L}L$	100.8	42.8	4.2	13.1	1.2	0.2	82	87.1	0.205	22	4.15
2	$\bar{L}U$	105.7	80.6	17.5	51.4	9.6	3.3	162	188.2	0.451	57	4.46
	\bar{X}	103.4	66.1	11.5	35.3	6.0	1.9	126	151.6	0.361	43	4.26
	$\bar{L}L$	101.1	51.6	4.6	19.2	2.4	0.5	90	115.0	0.271	29	4.06
3	$\bar{L}U$	107.6	87.0	18.0	59.2	11.6	3.5	178	209.9	0.487	64	4.43
	\bar{X}	104.5	70.6	12.2	41.6	7.8	2.0	136	167.5	0.395	50	4.23
	$\bar{L}L$	101.4	54.2	6.5	24.0	4.0	0.5	94	125.1	0.303	34	4.03
4	$\bar{L}U$	110.0	92.4	19.0	66.3	13.8	3.6	182	227.9	0.509	73	4.39
	\bar{X}	106.1	75.1	14.1	46.2	9.2	2.1	138	185.3	0.419	59	4.19
	$\bar{L}L$	102.2	57.8	6.8	26.1	4.6	0.6	94	142.7	0.329	47	3.99
B. 100-Barrel Lots												
0	$\bar{L}'U$	101.5	7.8	2.7	19.7	2.0	1.3	122	13.5	0.061	2	4.80
	\bar{X}	101.4	6.8	2.0	18.2	1.7	1.2	118	11.4	0.048	1	4.76
	$\bar{L}'L$	101.3	5.8	1.3	16.7	1.4	1.1	114	9.3	0.035	0	4.72
1	$\bar{L}'U$	102.2	58.3	11.4	28.1	4.3	1.8	128	126.6	0.315	38	4.30
	\bar{X}	102.1	56.9	10.8	26.8	4.0	1.7	124	123.1	0.305	37	4.29
	$\bar{L}'L$	102.0	55.5	10.2	25.5	3.7	1.6	120	119.6	0.295	36	4.28
2	$\bar{L}'U$	103.6	67.5	12.1	36.8	6.3	2.0	130	155.1	0.370	44	4.28
	\bar{X}	103.4	66.1	11.5	35.3	6.0	1.9	126	151.6	0.361	43	4.26
	$\bar{L}'L$	103.2	64.7	10.9	33.8	5.7	1.8	122	148.1	0.352	42	4.24
3	$\bar{L}'U$	104.8	72.0	12.7	43.3	8.2	2.2	140	171.6	0.404	50	4.25
	\bar{X}	104.5	70.6	12.2	41.6	7.8	2.0	136	167.5	0.395	49	4.23
	$\bar{L}'L$	104.2	69.2	11.7	39.9	7.4	1.8	132	163.4	0.386	48	4.21
4	$\bar{L}'U$	106.5	76.8	14.6	48.2	9.7	2.2	142	189.5	0.428	61	4.21
	\bar{X}	106.1	75.1	14.1	46.2	9.2	2.1	138	185.3	0.419	60	4.19
	$\bar{L}'L$	105.7	73.4	13.6	44.2	8.7	2.0	134	181.1	0.410	59	4.17

^a A. J. Lieberman and M. Rosenblatt, *Ind. Eng. Chem.*, **35**, 994 (1943). All figures expressed as grams per 100 liters at 100 proof, except proof (expressed as degrees proof), color (expressed as density), and pH.

^b $\bar{L}U$ = probable maximum = $\bar{X} + 2\sigma$; $\bar{L}L$ = probable minimum = $\bar{X} - 2\sigma$; \bar{X} = average; $L'U$ = probable maximum = $\bar{X} + 2\sigma\bar{X}$; $L'L$ = probable minimum = $\bar{X} - 2\sigma\bar{X}$.

doubler, and in continuous stills and doubler, and all stored in new, charred white oak barrels and aged in various kinds of whisky warehouses under the usual range of conditions of aging. No matter what form of still is used for whisky if it is distilled at about the same proof and aged in the same sort of package, the acids (fixed and volatile), esters, color, aldehydes, furfural, and ash will be nearly the same. This has been

shown by analysis. Fusel oil is the only component which will differ depending on the proof of distillation and to some extent the type of still and its method of operation.

The results of a study of whisky by Valaer and Frazier over a period of years may be summarized as follows:⁶ The largest increase of acids, esters, solids, and color occurred during the first six months of storage. The acids and esters did not reach a ratio of 1:1, and the analyses showed no fixed relationship between these two compounds as found by Crampton and Tolman,⁷ at the end of four years. There was an actual as well as an apparent gain in acids over the four-year period using data calculated to original volume. The actual acid gains were from 24.9 to 56 g. per 100 liters (average 40.1). There was an actual as well as an apparent gain in esters over the four-year period when calculated to original volume. The esters actually gained from 7.4 to 21.3 g. per 100 liters (average 15.5). There was an actual loss of fusel oil during the aging period, from 6.9 to 58.4 g. per 100 liters (average loss 28.6) when calculated to original volume. Quick aging increased the color, solids and acids. Whisky changes while standing in glass. There is usually a decrease in acids and a tendency for esters to increase. There is often an increase in color. A definite change took place in the newly distilled whisky that stood four years in glass; it lost practically all of its slop taste and odor. The components are continually undergoing changes as the aging process progresses, as found by Crampton and Tolman. The increase in acids in charred barrels is due partly to fixed acids extracted from the wood but mostly to the formation of volatile acids during the aging process.

The results of the observation of 108 bbl. of whisky under normal maturing conditions have been chemically and statistically analyzed by Liebmann and Rosenblatt.⁸ Table 69 summarizes the analytical characteristics of normal whisky during four years of maturing showing the average values X and the maximum and minimum normal variation among individual barrels to be expected in each case (L_U and L_L).

4. Scotch Whisky

The most important imported alcoholic beverage is blended Scotch whisky, which has held the lead in volume and value for many years. The largest volume imported in any one year (1939) was 7.6 million cases (2.4 gal. per case). During 1941 and 1942 there was a gradual fall of blended Scotch importations. The war curtailed production and there were numerous sinkings, but in spite of these serious handicaps, 3,000,000 cases (2.4 gal. per case) were imported in 1941.

No doubt Scotch whisky is the original whisky, as is claimed by some authorities. It has, however, gone through a few changes since its origin. Up to about 1831 it was uniformly a pot still product. About that time the continuous Coffey still was patented. This still consists essentially of two columns, a rectifier and analyzer, and yields a distillate of 90–94% alcohol content. This very light distillate, called Scotch grain

⁶ P. Valaer and W. H. Frazier, *Ind. Eng. Chem.*, **28**, 92 (1936).

⁷ C. A. Crampton and L. M. Tolman, *J. Am. Chem. Soc.*, **30**, 98 (1908).

⁸ A. J. Liebman and M. Rosenblatt, *Ind. Eng. Chem.*, **35**, 994 (1943).

spirits, was found to blend well with the pot still distillate and to give a liquor that had a definite but less marked taste and aroma. Soon practically all of the Scotch whisky was blended and imported as blended Scotch whisky.

In Scotland there are four classes of unblended pot still Scotch malt whiskies: the Highlands, the Islays, the Lowlands, and Campbelltown, each named for its Scottish place of production. While there is a slight difference between them, principally in the amount of burned peat flavor, after they have been mixed in the different proportions with about 65% by volume of Scotch grain spirits very little difference is noticeable. Blended Scotch whisky is a uniform product, differing only in peat flavor, according to the desires of the blender. This flavor is obtained by allowing the green or

TABLE 70
ANALYSES OF IMPORTED SCOTCH WHISKIES, BLENDED AND BOTTLED IN SCOTLAND^a

G. per 100 liters (not calc. to proof)											
	Proof	Total acids	Volatile acids	Esters	Higher alcohols	Solids	Aldehydes	Furfural	Color, 1/2-in. cell	pH	Age, years
A. 23 Older Samples, 1934-1935											
Av.	87.2	21.0	16.6	20.6	49.2	140	5.6	0.7	9.6	4.23	9
Max.	87.9	33.6	25.2	28.6	88.0	206	10.3	1.6	13.0	4.48	12
Min.	85.2	16.8	12.0	16.7	35.2	102	2.4	0.4	7.5	4.00	4
B. 74 Authentic Samples Analyzed August, 1939											
Av.	87.2	21.4	16.6	19.5	63.9	141	6.0	0.7	8.2	4.38	10
Max.	94.5	34.8	28.8	29.0	114.0	216	9.2	1.5	12.0	4.78	17
Min.	84.7	8.4	6.0	13.2	42.2	88	1.5	0.3	4.0	4.10	8 ^b
C. Samples Representing All of the All-Malt Unblended (with Scotch Grain Spirits) Scotch Whisky Imported from Scotland in 1939-1940 in Commercial Bottles (or Wholesale and Retail Trade)											
112	92.4	25.2	21.6	26.4	129	114	5.9	1.5	4.0	4.68	12
116	86.7	26.4	24.0	29.0	117	132	7.9	1.2	7.0	4.78	No age given

^a P. Valaer, *Ind. Eng. Chem.*, 32, 935 (1940). All of these imported Scotch samples were taken from authentic regularly imported packages and contained caramel coloring.

^b No lower age stated.

partially dried malt to absorb some of the empyreumatic emanations from the smoldering peat used in drying the malt. This flavor, dissolved by the mash, passes over into the distillate and imparts the characteristic smoky flavor so essential to Scotch whisky. The Scotch grain spirit used for blending is actually a very light-bodied corn whisky.

A moderate amount of Scotch pot still malt whisky is imported into the United States for the use of rectifiers in producing blended Scotch-type whisky. This mixture, made outside of Great Britain, consists of not less than 20% by volume of 100° proof malt whisky or whiskies distilled in pot stills at not more than 160° proof, from a fermented mash of barley malt dried over peat fire, and not more than 80% by volume of neutral spirits or whisky distilled at more than 180° proof, whether or not such proof is subsequently reduced prior to bottling to not less than 80° proof. Only very little pot still malt whisky or Scotch grain whisky is imported to be consumed unblended.

TABLE 71
ANALYSES OF SCOTCH-TYPE WHISKIES^a

	Proof	Total acids	Volatile acids	Esters	Higher alcohols	Solids	Aldehydes	Furfural	Ash	Color, $\frac{1}{2}$ -in. cell	pH	Age, years
<i>A.</i> Blended Scotch-Type Whisky Made in U. S. in 1939 ^b												
Av.	85.3	12.1	8.8	8.9	26.2	286	2.2	0.4	7	7.3	4.81	10
Max.	88.2	26.4	20.4	19.4	45.8	1394	4.7	1.8	16	10.5	6.22	15
Min.	80.2	2.4	1.2	4.4	12.3	54	1.0	Trace	0	3.5	4.00	6
<i>B.</i> Imported Scotch Malt Whisky to Be Used in Domestic Blended Scotch-Type Whisky ^c												
Av.	111.2	50.0	39.3	41.1	129.7	210	9.2	1.9	9	10.6	4.30	11
Max.	129.2	78.0	68.4	60.7	190.1	485	15.5	4.0	20	20.0	4.60	18
Min.	84.5	31.2	21.6	17.6	84.5	64	1.6	1.0	0	3.0	3.83	6
<i>C.</i> Comparison of Scotch Malt Whiskies and Blended Scotch-Type Whiskies Made from Them												
Av. 10 malt whiskies	112.2	42.5	35.5	36.3	134.4	189	8.5	1.9	10	9.7	4.41	10
Av. 10 blends	86.2	11.6	8.3	8.9	28.9	349	2.1	0.5	6	7.3	4.74	10

^a P. Valaer, *Ind. Eng. Chem.*, **32**, 935 (1940).

^b All samples examined were colored with caramel. The amount of Scotch malt used in the seventy blends was 20-30%. Mostly Islay malts were used, some Highland malts, no Lowland or Campbeltown.

^c 30 of the samples contained caramel coloring, 11 contained traces of caramel, and 7 contained no caramel.

5. Irish Whisky

In 1937-1938, fourteen distilleries were making pot still whisky in Ireland, three of them using all-malt barley. The next important ingredient is unmalted barley; in much smaller amounts, rye, wheat, and oats are also used. Since no peat is utilized in drying the malt, there is no smoke flavor.

The mashing, fermenting, and distilling are conducted in about the same manner as in Scotland, except that the pot stills are larger and, although mostly fire heated, may also be reinforced with steam coils. Irish whisky is usually distilled three times, and the whisky is stored at a higher proof (132-135 U. S.) than Scotch whisky. The cooperage is about the same as in Scotland. It is bonded at 25 over proof British (143° U. S. proof).

6. Gin

Gin was originally produced in Holland and was distilled from a fermented mash of grain, principally barley, along with juniper berries and other aromatics. It had the body and character of new whisky plus the aromatic flavor and character of gin. It was called Holland or Scheidam gin. A small amount of this kind of gin is made in the United States.

The principal form of gin is distilled gin, English gin, or London dry gin. Large quantities of this product are made, ranking next to whisky in volume of beverage spirits. About 12,000,000 tax gal. were produced during the fiscal year ending June 30, 1941, and 13,000,000 tax gal. during the fiscal year ending June 30, 1942. During 1942, the production of gin was curtailed because the neutral spirits required for its manufacture had to be diverted to the production of war munitions.

Distilled gin is produced by distilling diluted commercial neutral spirits with distilled water, usually to about 120° proof (40% water, 60% alcohol). A large copper pot still is usually employed, into the head of which is placed one or more trays, bags, or other receptacles containing juniper berries, coriander seeds, angelica, and other aromatics including herbs, berries, seeds, and barks. During distillation the alcohol-water vapors pass through and over the aromatics and extract the flavoring principles. They are condensed together in the cooling worm. The distillate is then reduced to the desired proof with distilled water and bottled. Aging in any sort of container is not required and may even be harmful—the essential oils of the gin gradually decompose, producing a disagreeable terpene character. Gin is nearly always water-white in color. This is the type which is produced in the largest volume.

The neutral spirits used for gin is the same as that used to blend with straight whisky for producing spirit blends. If the neutral spirits used in either case is that obtained from fermented cane juice or molasses, it must be declared on the label. If neutral grain spirits is used, no statement is required. If the gin is produced by simply adding flavoring ingredients to the diluted spirits, the gin prepared in this manner is known as compound gin. It must be produced only by a qualified rectifier and the product must bear a special tax of 30 cents per proof gallon. Due to the requirements of

TABLE 72
ANALYSES OF REGULARLY IMPORTED IRISH WHISKY,^a 1935-1940

Serial No.	Proof	Total acids	Volatile acids	Esters	Higher alcohols	Solids	Aldehydes	Furfural	Color, 1/4-in. cell	pH	Age, years	Type
54502	91.2	24	22.8	23.8	153	114	3.2	2.0	6 ^b	4.37	7	Pot still
54589	91.0	16.8	10.8	20.2	145	162	4.8	2.0	6.5 ^c	4.67	10	Pot still
54590	85.8	16.8	14.5	18.5	155	162	1.6	1.6	10.0 ^c	4.25	10	Pot still
54595	86.8	19.2	15.6	22.0	173	222	5.6	1.0	8.5 ^c	4.60	9	Pot still + grain
95846	91.2	38.4	27.6	28.2	165	138	14.9	8.0	6.0 ^b	4.33	15	Pot still
3067	124.7	22.1	20.4	40.6	172	24	9.6	2.2	1.7 ^b	4.55	8	North of Ireland pot still
3063	118.8	21.6	15.6	21.9	225	83	9.1	5.0	6.7 ^c	4.48	8	Pot still
3064	120.0	19.6	14.2	18.7	235	113	7.2	3.3	4.8 ^c	5.06	8	North of Ireland grain ^d
3062	127.2	14.2	12.0	19.3	33.2	28.8	5.3	0	2.4 ^b	4.57	8	North of Ireland grain ^d
3065	134.9	16.2	13.1	20.9	28.7	46.7	5.7	Trace	3.2 ^b	4.56	8	North of Ireland grain ^d

^a P. Valaer, *Ind. Eng. Chem.*, 32, 985 (1940). Samples furnished by the Whisky Association (London), taken directly from aging casks, supported by certificate of origin.
^b No caramel.
^c Caramel.
^d The Irish grain whiskies both have a light whisky character.

TABLE 73
ANALYSES^a OF 25 GREEK GRAPE BRANDIES IMPORTED IN 1937-1938^b

Range	True proof	pH	G. per 100 liters (not calc. to proof)					Furfural	Color, 1/4-in. cell	Color tests	
			Total acids	Volatile acids	Esters	Fusel oil	Solids				
Max.	94.0	5.77	103.2	70.8	79.2	121.4	4,040	23.6	2.4	26.0	Caramel with age color
Av.	89.1	4.41	51.94	33.76	40.5	58.0	1,651	13.8	1.0	15.1	Caramel with slight age color
Min.	81.0	3.28	21.6	6.0	7.9	10.6	198	4.0	Trace	8.0	All caramel

^a P. Valaer, *Ind. Eng. Chem.*, 31, 339 (1939).

^b Because of the relatively high solid content, the ordinary hydrometer gave only an approx. estimate of the alcoholic contents. The aberration due to added material was sometimes as much as 17° proof. The aged-in-wood color was usually absent or present in very small amounts. The methanol content varied from a mere trace to 0.05%; it was generally less than in any other brandy. The various ages claimed were from 4 to 25 yrs. Three samples contained a solid content of 198, 202, and 204 g. per 100 liters. These products were specially made to meet the American standards for straight brandy.

labeling and the extra tax, very little compound gin is produced legally. The most significant requirement for gin is that it must derive its main characteristic flavor from juniper berries.

Gin is, comparatively, the easiest alcoholic liquor to produce. The chemical composition is practically that of diluted neutral spirits, the only change in composition being the acquisition of small portions of aromatic principles which are very difficult to determine chemically and are still more difficult to identify.

When the gins described above are sweetened, the products become cordialized and are called "Tom Gin" and other fanciful designations. The most frequent forms of adulteration are found in "compound" or "bath tub" gin sold for distilled gin, in the failure to label as such gin made from cane spirits, in the deficiency of gin in Juniper flavor and the substitution of other oils and aromatics for Juniper.

7. Brandy

It is known that, in 1313, a French alchemist and physician designed a device to distill wine into brandy. It became a general practice during the 15th and 16th centuries in France to distill wine for the purpose of "concentrating" its volume to preserve space and to facilitate its transportation.

Brandy can be made from any fruit. For this reason, the sources of brandy are numerous, for where fruit is grown in any quantity some of it may be fermented and distilled into brandy. In some countries "brandy" refers only to the distillate from grape wine. In the United States and other countries which grow large quantities of other fruits, the fermented juices of these other fruits are also utilized for brandy.

Of all the distilled beverage spirits produced and stored in the United States, brandy ranks next to whisky and gin in quantity. About 3,000,000 gal. of all kinds of commercial or beverage brandy, most of which is grape brandy, is the normal yearly output in the United States. At the same time, about ten times as much high-proof (185-189° proof) or wine spirits is distilled for the purpose of increasing the alcoholic content of sweet wines. Brandies for use as wine spirits in the production of dessert wines are made from wine, wash from grape pomace, or from the pomace itself. California, with more than 80% of all the brandy made in the United States, is the largest producer in the world. In California, practically all brandy (99%) is grape brandy, whereas in other States brandy is made largely from other fruit.⁹

In normal years, France is the leading brandy exporter into the United States. French cognac (about 700,000 gal. during ordinary years) has an overwhelming lead over all other foreign types of brandy. Since the second World War, Spain increased its exportation of brandy to the United States, but the amount is relatively small, about 50,000 gal. per year, with Portugal, South America, and South Africa also supplying some. All cognac, Italian, and Greek brandy shipments have been temporarily discontinued.

During normal times brandy can be classified in groups, geographically, along broad

⁹ M. A. Joslyn and M. A. Amerine, Univ. of Calif. Agr. Expt. Sta., *Bull.* 652 (Sept., 1941).

lines in order of the quantity of production or importation into the United States: (1) California grape brandy; (2) French cognac brandy; (3) American apple brandy; (4) Greek brandy; (5) Spanish brandy; (6) Italian brandy; (7) South American brandy; (8) South African brandy; and (9) miscellaneous American fruit brandies, not apple or grape, but including all other fruit brandies, principally peach, pear, raisin, prune, apricot, cherry, blackberry, and others.

During the 17th and 18th centuries, the California Mission Fathers first distilled grape brandy from crude pot stills. At the present time there are over a hundred brandy distilleries in the State, equipped principally with the Krenz type of continuous still. Some of these stills are very large, with 60 or more chambers producing up to 400 gallons of brandy per hour. There are a few pot stills in operation and some other types of continuous stills.

For every 38 proof gal. of beverage brandy produced, about one ton of grapes are used. It is estimated that about 99% of the total brandy produced in California is grape brandy. In California, the grapes as received are sent to the stemmer and crusher; this must, including all of the crushed grapes to be used for brandy, is fermented completely dry on the skins. The fermented juice is drawn off, water is added to the fresh pomace, and all the remaining juice is pressed out. This distilling material is immediately distilled. The dry pressed pulp may be used for other purposes or discarded. Pure wine yeast cultures are used, but some fermentations are still being conducted without any added yeast. Occasionally wines of all ages may be distilled into brandy, but more often when any wine is distilled it is because, for numerous reasons, it is not suitable as wine. This sort of wine seldom makes passable beverage brandy, but a high-grade fortifying brandy can be produced from it; if it is distilled at about 185-190° proof, it is pure, neutral and has hardly any of the characteristics associated with beverage brandy.

The chief distinction between high-proof or wine spirits and commercial or beverage brandy is the proof of distillation.

Much better material is used and more care taken in its preparation if the final brandy is intended for the best commercial brandy. On the other hand, because of the high proof of distillation, many objectional impurities which develop from the growth of microorganisms during fermentation and in storage can easily be eliminated in the "heads and tails," the principal product being almost pure alcohol with some slight fruit brandy character. In order to have a sufficient commercial brandy character, the proof of distillation should range from 155 to 170°—the lower the proof the more brandy character.

For the distillation of brandy there are two main types of stills, the pot still and the continuous still.

The pot still product is richer in brandy character, but if the material to be distilled is not of the highest order, it may not be good-quality brandy. The initial boiling component in the pot comes off as "heads" containing as the principal objectional substances, acetaldehyde and if present, sulfur dioxide. The last portions of the vapors evolved contain the constituents with higher boiling points, principally higher alco-

hols. For these reasons, the distillation of pot still brandy usually is separated into three divisions—heads, the brandy, and the tails. For economical purposes the heads and tails are redistilled for any brandy it may have. The proof of distillation of pot still brandy is rarely over 160° proof. With the present-day continuous brandy still, the complications of the pot still are eliminated and the operation may be made faster and more efficient, even on a vastly larger scale. Generally speaking, the number of plates determines the proof of the brandy obtained, while the diameter of the still usually determines its capacity. In the continuous still, the distilling material is injected approximately into the center of the column, steam being supplied to the lower chamber. The vapors pass through the column into a partial condenser or dephlegmator, and thence to the condenser, the condensed liquid then being run into the receiving tanks.

The continuous still installations of larger sizes necessitate taking care of the fusel oil, principally amyl alcohol, which continually collects near the center of the still during its operation. The higher boiling components collect in the mid-section of the still because they are insoluble both in water and in the higher concentrations of brandy. This fusel oil is drawn from a number of selected plates and run into a cooler, then to a decanter where it is separated out by the use of water. The distilling material for a continuous still is preheated by various devices in which the heat of the spent dealcoholized slop from the bottom of the still is utilized.

(a) *Apple and Other Fruit Brandies*

Probably one of the oldest and most typical of American industrial distillations is the production of apple brandy, commonly known as applejack. Apple brandy was produced and sold commercially even before the American Revolution. The present production is about half a million proof gal., one-half of which is distilled in New Jersey, and most of the remainder in California, Virginia, Washington, and Oregon.

The process of production is quite simple. The carefully selected, ripe, washed apples are finely ground and pressed into juice. After the usual natural fermentation, the hard cider is allowed to settle, and the clear fermented liquid is racked or filtered. The fermented cider is usually distilled at once, but in flush season and when stills are not immediately available the hard cider is stored and distilled when convenient. Although some continuous or column stills are used for the distillation of apple brandy, as in California and Oregon, most of the apple brandy is distilled in pot stills or some simple modification, particularly in Washington State and in the East, where all of the apple brandy distilleries are relatively small. The principal method is to distill the fermented apple juice into low wines in the simple pot still, the proof being about 60°. The low wines are then redistilled into brandy of about 110–133° proof. Usually the head and tails of the second distillation are eliminated. The total distillate is run into a cistern, where it is cut under the supervision of a government gager to about 105° proof and filled into white oak barrels which are usually new charred, but may be re-used charred, new plain, or re-used plain.

In the distillation of all other fermented fruits, such as peaches, apricots, and a large variety of other fruits, the procedure is more often like that described for apple brandy and only rarely like that described for grape. Often the whole fruit is crushed, fermented, and distilled directly. This sort of brandy has a flavor highly characteristic of the fruit; and the methanol, which is present in all brandy, may reach a concentration as high as $\frac{1}{2}$ of 1%.

(b) *Foreign Brandy*

France.—The best known of the brandies shipped to the United States is *eau de vie de Cognac* or, as it is popularly known throughout the world, "cognac". About three-quarters of a million proof gallons are exported to the United States during normal times. Cognac is produced in the Charente District of France (Table 74, page 780) from a limited and a specified number of variety of grapes grown there by thousands of small-acreage farmers who produce the wine from the grapes and distill the wine into brandy as well. The brandy is distilled from 800 or more individual small, fire heated pot stills (a few steam heated) of capacities of 120 to 200 gallons. These small parcels of brandy are gathered by large collectors, blended into large, uniform masses adjusted to certain specifications, and filled into large re-used barrels, of 75-100 U. S. gallon capacity, for aging. The aging is conducted in damp storage buildings without windows. During this storage, the proof goes down rather than up. Because of the character of the grapes and the wine produced, and more particularly of the effect of the fire heated copper pot still on the wine and its lees, the brandy takes on a natural flavor rather different from that of any brandy produced elsewhere. This character is due to the cognac flavor, a very small amount of material which has been isolated from the brandy by repeated fractional distillation. It is formed during the pot still distillation by fire action on the lees material.

The general procedure in producing cognac brandy is to distill 3 or 4 portions of wine separately. These first distillations are combined for a second distillation. There is about 30% alcohol in the first distillations, while the average proof in the second distillation is about 100°. Over 4,500,000 gal. of cognac are normally produced yearly, leaving about 20,000,000 gal. aging in France.

Armagnac brandy takes its name from the region of France in which it is produced. The process of making Armagnac brandy is similar to that of producing cognac. While, to many, the character of the two brandies appears to be the same, generally speaking cognac has considerably more of the characteristic *cognac* flavor. These two types are never blended legally.

Greece.—Both pot stills of the French type and continuous stills are used in Greece to produce brandy which is made from many varieties of sweet grapes (Table 73, page 775). The aging is carried out in very large vats and in the wood used for storage. Aging during transportation has been a practice for a long time. The Greeks customarily rectify their brandies with added substances. Furthermore, caramel coloring and other factors tend to give Greek brandy a special character.

TABLE 74
STANDARD FRENCH BRANDIES AS IMPORTED IN 1938^a

Range	True proof	A.p.-parent proof	G. per 100 liters (not calc. to proof)								Ash	Methanol, %	Color, 1/2 in. cell
			pH	Total acids	Volatile acids	Esters	Fusel oil	Total solids	Aldehydes	Furfural			
<i>A.</i> French Cognac (20 samples) ^b													
Min.	79.1	73.8	3.76	26.4	21.0	36.1	89.8	624	6.3	1.0	6.0	0.011	12.5
Av.	84.6	80.7	4.14	51.5	34.2	44.3	103.9	975	8.6	1.3	12.7	0.017	17.2
Max.	88.2	82.2	4.98	110.4	72.0	58.1	127.0	1,368	14	3.0	28.0	0.027	26.0
<i>B.</i> French Armagnac													
Min.	84.4	80.4	3.70	62.4	43.2	49.3	91.5	886	8.7	0.6	19.0	0.021	12.5
Av.	84.8	81.0	3.77	64.0	43.2	52.8	94.4	929	9.1	0.7	19.0	0.026	15.8
Max.	85.8	82.2	3.88	67.2	45.6	59.8	96.8	962	9.5	1.0	20.0	0.031	17.5

^a P. Valaer, *Ind. Eng. Chem.*, 31, 339 (1939).

^b Analyses of 20 authentic Charente cognac brandies include all usual qualities and ages, and bear the general quality and age letter brands, such as 3 Star, 5 Star, XO, V.S.O.P., V.E., V.F.C., V.V.S.E.P., E.S.T.I.P., S.V., etc. The ages are from 3 to 50 yrs. All are colored with caramel, which constitutes most of the color, but have some aged-in-wood color as well. The ash is distinctly brown and rich in iron content. It is believed that most of this inorganic ash material was dissolved during storage in glass bottles, which were dark colored in all cases.

Spain.—During 1941 and 1942, because of the second World War, with the consequent curtailment of cognac import, Spanish brandy became the most important imported brandy. It is not made by a large number of small stills, as in France, but by a comparatively few large distillers, who must produce, besides beverage brandy, very large quantities of high-proof brandy required for fortifying the immense amount of sherry and other dessert wines for which Spain is noted. While there is, no doubt, a good deal of pot still brandy produced in Spain, practically all the Spanish brandy that has been imported has been distilled at a very high proof without much fruit flavor. Nearly all the recent imported Spanish brandy has been blended with sherry wines or material giving it all the same general character by which it may be recognized. It is generally lighter in natural components and heavier than other brandies in added material.

"Brandy has more sources than any other class of distilled spirits made in the United States and may be divided into two classes, grape brandy and fruit brandy. American grape brandy is produced from grape wine and is distilled mostly in continuous stills. It is almost always artificially colored with caramel and aged generally in new plain white oak barrels. Fruit brandy is made more often from apples, but includes the distillate from many other fruits and berries. Fruit brandy is usually made in other States than California, which produces practically all the grape brandy of the United States. Fruit brandy is generally distilled in pot stills at a lower proof than grape brandy and is aged principally in charred barrels from which it obtains its color.

"As far as can be determined there is a small amount of methanol in all authentic brandy; grape brandy contains an average of less than 0.05 per cent and fruit brandy, an average of about 0.1 per cent. Fruit brandy ages and develops congeners and extracts color and solids at about the same rate as whisky and rum in the same sort of package. Grape brandy in the plain packages changes more slowly and more gradually.

"French Cognac brandy is in a class of its own. It is clearly distinguished by a uniform and unique character not found in any other brandy. American grape, apple, and other fruit brandies are distinct from any other brandy in that they possess the unmistakable natural flavor and pleasant aroma of the fresh fruit from which they are distilled. This flavor is not lost but rather enhanced during natural aging.

"Of the various groups of congeners characteristic of brandy, the esters are of most importance and are generally more abundant in brandy than in any other distilled spirit."

The following statements regarding brandies are also of interest:

- "1. The difference between the brandies made in France, Greece, Spain, California, and other parts of the United States is easily distinguishable.
- "2. The esters appear to be the most important natural ingredient from which brandy derives its general characteristics.
- "3. The kind of cooperage has much to do with the quality and flavor of brandy. Charred barrels usually furnish too much wood flavor, re-used barrels barely enough. New plain barrels are the standard containers for the storing and aging of grape brandy.

XXIV. ALCOHOLIC BEVERAGES

TABLE 75
CHANGES TAKING PLACE DURING STORAGE OF CALIFORNIA BRANDIES*

Sample No.	Date taken	Proof	pH	G. per 100 Liters (not calc. to proof)								Color, 1/2-in. cell	Approx. age
				Total acids	Volatile acids	Esters	Fusel oil	Solids	Astu	Aldehydes	Furfural		
U. S. Brandy No. 1 (Serial No. 7724)^b													
50592	10-31-34	100	6.78	3.6	24.6	75.2	57.8	9.0	2.0	0	5	New	
57282	5-22-35	100	5.50	9.6	7.2	25.8	76.6	68.0	6	3.0	0	4.5	6 mo.
63728	12-20-35	100	5.12	14.4	13.2	26.0	77.2	70.0	6	3.2	0	5.0	1 1/2 yr.
71107	7-8-36	100.6	5.00	16.8	15.6	26.3	77.4	79.2	7	3.4	0.14	5.0	2 1/2 yr.
74256	11-18-36	101.5	5.00	19.2	18.8	26.3	79.2	72	6	3.4	0.16	5.0	2 1/2 yr.
77919	5-6-37	101.5	4.92	21.6	20.4	26.4	82.2	82	9	3.0	0.2	5.5	3 1/2 yr.
83420	11-3-37	101.6	4.85	24.0	21.6	29.0	82.7	84	6	3.3	0.3	5.5	3 1/2 yr.
88995	5-3-38	102.3	4.83	26.0	22.8	30.4	83.5	88	17	3.5	0.4	6.0	4 yr.
93456	11-3-38	102.8	4.82	27.6	25.3	31.7	84.5	94	4.0	3.7	0.4	6.0	4 yr.
U. S. Brandy No. 2 (Serial No. 2107)^c													
51370	11-17-34	100.3	5.35	8.4	7.2	40.5	79.2	65.6	27	2.0	0.5	2.5	
56883	5-16-35	101.8	4.01	40.8	32.4	44.9	83.1	104	19	6.0	0.7	5	
64995	1-9-36	102.8	3.96	62.4	46.8	58.1	85.3	172	17	7.9	1.4	10	1 1/2 yr.
71106	7-10-36	103.4	3.95	67.2	49.2	58.9	86.2	180	16	7.7	1.4	10.5	1 1/2 yr.
74259	12-3-36	103.4	3.93	69.6	52.8	59.8	88.9	194	18	7.8	1.4	10.5	2 1/2 yr.
77964	5-4-37	104	3.92	74.4	56.4	62.5	100	198	21	8.4	1.2	11.5	2 1/2 yr.
83289	11-4-37	104.6	3.91	76.8	62.2	66.6	102	214	15	9.8	2.0	12.0	3 1/2 yr.
88992	5-3-38	104.6	3.91	76.8	64.8	67.8	103.4	215	15	10.8	2.0	13.0	3 1/2 yr.
93285	11-3-38	105.1	3.90	79.2	65.4	71.3	104.3	230	14	11.2	2.0	13.5	4 yr.
U. S. Brandy No. 3 (Serial No. 18965)^d													
51368	11-10-34	100.3	6.48	4.8	3.6	47.5	63.4	42.6	8	4.2	0.3	4	
56885	5-11-35	99.4	4.67	16.8	15.6	47.5	64.1	58.0	7	5.3	0.5	4.5	
64239	11-12-35	99.8	4.55	43.2	32.4	45.8	66.3	84.1	8	6.9	1.0	5.5	1 yr.
71111	5-12-36	99.8	4.52	40.8	36.0	49.3	68.6	97.2	6	6.9	1.2	6	1 1/2 yr.
74254	11-12-36	100.9	4.46	48.0	42.0	49.3	70.1	104.0	7	8.1	1.2	6.5	2 1/2 yr.
77968	5-1-37	101	4.46	50.4	44.4	53.7	72.7	104.0	8	8.4	1.2	6.5	2 1/2 yr.
83287	11-2-37	102.4	4.45	55.2	50.4	53.7	75.7	118.0	7	8.5	1.2	7.0	3 1/2 yr.
88986	5-3-38	103.0	4.44	55.2	50.4	54.5	78.2	129	9	8.8	1.3	7.5	3 1/2 yr.
93294	11-3-38	104.2	4.43	60.0	54.0	57.2	79.2	144	6	9.7	1.5	7.5	4 yr.

U. S. Brandy No. 4 (Serial No. 4252)^e

77885	5-1-37	101.8	5.02	4.8	3.6	14.1	22.9	51	4	6.7	0.5	5	1 mo.
80648	8-3-37	101.0	4.63	25.4	21.6	14.1	24.6	73	3	8.4	0.6	5.5	4 mo.
81212	8-27-37	101.6	4.63	26.4	22.9	14.1	26.4	77	6	8.4	0.6	6.0	4 ¹ / ₄ mo.
84379	12-3-37	101.6	4.57	31.2	25.3	15.0	26.4	80	6	7.4	0.6	6.0	7 ¹ / ₄ mo.
86161	2-3-38	101.6	4.57	33.6	27.6	15.8	20.4	88	4	8.5	0.7	6.0	10 ¹ / ₄ mo.
89024	5-2-38	101.4	4.55	38.4	28.8	18.5	28.0	92	5	7.5	0.7	6.5	13 ³ / ₄ mo.
91229	8-2-38	101.8	4.55	38.4	28.8	22.9	28.4	92	5	7.8	0.8	6.5	16 mo.
93230	11-2-38	101.9	4.53	40.8	36.0	22.8	28.6	98	6	8.9	0.8	7.0	19 mo.

U. S. Brandy No. 4 (Serial No. 3744)^f

75649	2-24-37	101.8	5.04	9.6	9.6	29.9	66.4	2	2	16.6	Trace	0.2	3 mo.
77883	5-1-37	101.8	4.87	9.6	9.6	31.6	66.9	8	7	16.5	0.3	0.2	6 mo.
80646	8-3-37	101.4	4.65	12.0	12.0	31.7	66.9	8	5	16.3	0.7	0.3	9 ³ / ₄ mo.
81210	8-27-37	102.0	4.65	19.7	19.2	31.2	66.4	8	3	16.3	0.7	0.3	9 ³ / ₄ mo.
84377	12-3-37	102.2	4.60	19.2	14.4	33.0	66.4	11.0	5	16.1	0.8	0.3	12 ³ / ₄ mo.
86163	2-3-38	102.2	4.62	19.2	15.6	35.0	66.4	14.0	6	16.1	0.8	0.3	15 ³ / ₄ mo.
89022	5-2-38	102.2	4.60	21.6	16.8	36.0	66.9	14.0	3	16.2	0.8	0.4	18 ³ / ₄ mo.
91227	8-2-38	102.4	4.60	24.0	19.2	36.1	66.9	22.0	3	16.2	0.8	0.5	21 ³ / ₄ mo.
93226	11-2-38	102.6	4.60	26.4	24.0	36.1	66.9	22.0	4	16.2	1.0	0.5	24 mo.

U. S. Brandy No. 5 (Serial No. 6113)^f

72948	10-16-36	101.8	5.39	8.4	8.4	21.0	71.0	70	12	13	0.4	7.5	New
75258	1-29-37	101.8	4.95	16.8	15.6	22	72.2	92	14	13.2	0.6	7.5	3 mo.
77886	5-3-37	101.8	4.50	24.0	20.4	26.4	73.0	99	11	12.4	0.8	7.5	6 mo.
80781	10-3-37	102.0	4.47	33.6	30.0	27.3	73.7	112	12	13.1	1.2	7.5	12 mo.
85870	2-1-38	102.0	4.48	45.6	39.6	29.9	78.9	118	13	13.9	1.4	8.0	15 mo.
88956	5-2-38	102.5	4.46	48.4	41.0	33.4	74.2	122	9	12.4	1.0	8.0	18 mo.
91379	8-2-38	102.8	4.45	50.4	45.6	34.3	75.4	128	8	13.1	1.0	8.5	21 mo.
93368	11-3-38	102.8	4.42	55.2	48.0	35.5	75.7	144	10	14.1	1.2	9.5	24 mo.

TABLE 75 (*Continued*)

Sample No.	Date taken	Proof	<i>p</i> H	G. per 100 liters (not calc. to proof)					Aldehydes	Furfural	Color, $\frac{1}{2}$ -in. cell	Approx. age
				Total acids	Volatile acids	Esters	Fusel oil	Solids				
U. S. Brandy No. 6 (Serial No. 3493) ^b												
76301	3-9-37	101.2	4.87	24.0	19.0	15.0	10.6	62	7	3.6	4	5.0
77966	5-5-37	100.8	4.67	33.6	30.0	15.0	10.6	70	7	3.6	5	6.0
80703	8-5-37	101.0	4.50	48.0	40.8	20.2	10.6	106	9	4.5	6	7.5
83271	11-4-37	101.6	4.45	55.2	48.0	20.2	10.6	124	9	5.5	6	10.0
85989	2-2-38	102.0	4.40	60.0	48.0	22.9	10.6	128	8	5.8	6	10.3
88990	5-3-38	101.8	4.40	62.4	48.0	28.2	12.0	135	7	6.3	6	10.5
91543	8-3-38	102.8	4.38	64.8	55.2	29.3	12.3	148	7	6.3	6	18.0
93287	11-3-38	103.5	4.35	70.8	57.9	33.4	12.3	164	6	7.3	6	21.0
												24. mo.

^a P. Valaer, *Ind. Eng. Chem.*, **31**, 339 (1939).

^b Grape brandy made from wine distilled in a copper continuous still using beer column only and stored in re-used plain bbl. Brandy was colored with caramel at time of filling. Samples gave positive tests for methanol (0.05%). Ash was white and contained some iron; most of this inorganic matter apparently came from the bottle. The bbls. were set aside in U. S. bonded warehouses for experimental purposes. Proof of distillation, 168-178°. Exclusive of samples taken, 6.43 wine gal. of brandy were lost from the bbl. in 4 yrs.

^c Grape brandy distilled from wine in one continuous distillation at about 163° proof. Aged in new plain white oak bbl. and colored with caramel at time of filling. Samples gave positive tests for methanol (0.08%). Ash was white and due mostly to inorganic matter extracted from glass bottle as a sample and also to some matter extracted from the original bbl. during aging. Exclusive of samples taken, 8.44 wine gal. of brandy were lost from the bbl. in 4 yrs.

^d Grape brandy distilled in a copper continuous still at about 180° proof. Aged in new plain bbl. and colored with caramel at time of filling. Samples gave test for methanol (0.085%). Ash was white and due to inorganic matter extracted from the glass and also from the bbl. Solids in sample 51368 due to caramel. Exclusive of samples taken, 8.36 wine gal. of brandy were lost from the bbl. in 4 yrs.

^e Brandy distilled 4-8-37 from wine and then run through a Hebert continuous still at 188° proof. Aged in new plain bbl. All samples contained caramel coloring and gave positive tests for methanol (0.05%). Exclusive of samples taken, 4.47 wine gal. of brandy were lost from the bbl. in 19 mo.

^f Brandy distilled 11-19-36 from wine lees and pomace in pot still, cut in proof, and doubled through Hebert continuous still at 180-185° proof. Classified as grappa. Aged in paraffined bbl. Sample contained no caramel coloring. All gave positive tests for methanol (0.05%). Exclusive of samples taken, 1.1 wine gal. of brandy were lost from the bbl. in 2 yrs.

^g Brandy distilled at 177° proof and aged in new plain white oak bbl. Brandy was colored with caramel; gradual increase in color was due to aging in wood. It does not have the taste and aroma of French cognac. Samples gave positive tests for methanol (0.085%). The ash was pure white and gave a positive test for iron. The bbl. and the bottle probably both furnished this inorganic matter. Exclusive of samples taken, 4.44 wine gal. of brandy were lost from the bbl. in 2 yrs.

^h Brandy distilled at about 187° proof in a continuous still and aged in new charred white oak bbl. Light caramel coloring added, but color in older samples was due mostly to the aging in charred wood. It has not the taste and aroma of cognac or brandy. It is believed bbl. taste. Samples gave a positive test for methanol (0.09%). The ash was white and gave a small positive test for iron. It is believed that both the bbl. and the bottle furnished this inorganic matter. Exclusive of samples taken, 4.14 wine gal. of brandy were lost from the bbl. in 2 yrs.

"4. Brandy flavor, in general, is more delicate than that of other distilled spirits and is easily affected by impure water, certain metals, and improper wooden containers; it is rarely improved by the usual quick-aging methods.

"5. American brandy is distilled, aged, and bottled at higher proof than most other American or foreign distilled spirits.

"6. A small amount of methanol is apparently inherent in all authentic brandy; it is generally less in grape than in other fruit brandy.

"7. With the exception of apple brandy and some other fruits that are distilled at a low proof (well below 160) to obtain maximum flavor and are stored in new charred barrels for aging and to produce color, practically all other brandy, both foreign and domestic, is colored with caramel.

"8. Ethyl acetate is the most abundant and most easily formed ester during aging. The higher esters are formed more slowly and produce more characteristic flavors. Both ethyl acetate and higher esters are present in brandy at the time of distillation.

"9. Principally because plain white oak barrels are almost universally used for storing and aging grape brandy, the development of acids, esters, solids, color, and proof is less at any time during a four-year storage period than is the case in the aging whisky or rum.

"10. At least one important natural ingredient can be isolated from France's Cognac brandy which is not found in any other brandy and from which a great deal of the characteristic taste and aroma of cognac are obtained."¹⁰

During the vintage season of 1938 there were distilled 9,500,000 proof gallons of commercial brandy, about five times as much as in any previous year. Its quality was assured by requiring fresh, sound, ripe grapes, a low proof of distillation (average 167), new plain washed barrels, a standard color, and pure water. It will be nearer in character to brandies 2, 3, and 5 of Table 75.

Each of the six distilleries of the group shown in Table 75 set two barrels aside for aging, but the changes taking place during the aging in each set were so similar that it was considered necessary to show only the analysis of one barrel from each distillery.¹⁰

8. Rum

Rum is an alcoholic beverage distilled directly from fermented sugar-cane products and has no other source. The distillation of rum is principally performed in the semi-tropical islands of the West Indies, but is also produced in other countries where sugar cane is grown, or where molasses is shipped. It is believed that the earliest rum was made 3 or 4 centuries ago in the West Indies, where the juice begins to ferment vigorously almost immediately after being expressed because of the presence of wild yeasts. Rum was produced by the early New England settlers; by 1783 there were 60 small distilleries producing rum from imported molasses. It is reported that 7,000,000 gal. of molasses were imported for rum making in 1791.

Puerto Rico, because it holds a favored tariff position as a territory of the United States, has made more rapid progress than any other country in the production of rum. In 1943, a production of over 1.4 million proof gal. was reported. Virgin Islands produce about 0.4 million proof gal. Cuba, Jamaica, British Guiana, Trinidad, and Martinique (before the war) were producing large quantities of rum, and Mexico, Haiti, and Santo Domingo, a smaller gallonage, only a very small fraction of which was exported to the United States. For eleven months, July 1, 1941, to May 31, 1942,

¹⁰ P. Valaer, *Ind. Eng. Chem.*, 31, 339 (1939).

approximately 3,000,000 gal. of rum were produced in the United States, with 3,500,000 stocks on hand on June 29, 1942. This production is confined to three States, Massachusetts and Kentucky producing nearly the same in quantity, while a relatively small amount is made in Pennsylvania. Some of the stocks and current production will go to produce denatured rum used in tobacco products.

Rum is distilled, casked, aged, and analyzed in the same manner as whisky. The congeners, flavor, and color are developed at about the same rate and in the same manner as whisky. Taste and aroma are important factors in the ultimate judgment of rum. Rum steadily improves in character with aging, either in charred, plain, or re-used barrels or vats.

Puerto Rican rum and Cuban rum (Table 76) are very similar in character. They are made from molasses which is fermented quickly. The fermented material is distilled almost altogether in continuous stills, the usual proof of distillation being 160° to 185°; but some of this rum is distilled up to almost 190° proof and has only a very small amount of rum character. These two groups furnish the lightest of the commercial rums.

Most of the rum produced in the Virgin Islands (Table 77) is made on the largest island of the group, St. Croix, where its fertile lowland valleys furnish vast quantities of sugar cane. There are four rum distilleries on this island and they use only sugar-cane juice as fermenting material. The cane is crushed and the juice is hauled or pumped directly into fermenters as soon as possible in order to avoid too much premature fermentation. Distillation is conducted in pot stills and in continuous stills, with the proof usually ranging from 150° to 170°. The distillate is drawn off into charred barrels, and is usually blended before it reaches the market.

It is claimed that Jamaica was the earliest commercial producer of rum. The largest stocks of the oldest rum may be found there. Jamaica rum (Table 78) is the product of about thirty sugar estates. The molasses from these estates is fermented in the following manner: Diluted molasses (previously distilled slop), called "dunder," and a cane-juice yeast culture are allowed to ferment and form the "wash." This is distilled in a steam or fire heated pot still into vats, and then filled into 110 imperial gallon puncheons, usually plain. There is a tendency to prolong the fermentation in order to increase the ester content. This practice, with the use of dunder and the use of the pot still exclusively, has a tendency to make the imported Jamaica rum somewhat different in character from any other rum, foreign or domestic. Because of the nature of its fermentation Jamaica rum is not particularly desirable for drinking purposes when new, but improves tremendously during the relatively long aging process given it.

Rums produced in the United States (Table 79) may be classed as medium bodied, except at one Pennsylvania distillery, whose product may be classed as light. They have a full, rich flavor, which is rather raw and not desirable for drinking purposes when new; but they develop an excellent aromatic quality when aged in charred oak barrels. With the exception of the one Pennsylvania product, these rums are distilled below 160° proof as required for New England rum. Like St. Croix rum, they are distilled in pot stills and continuous stills.

TABLE 76
ANALYSES OF AUTHENTIC CUBAN RUMS^a

Lab. No.	Proof	pH	G. per 100 liters (not calc. to proof)						Depth of color, $\frac{1}{2}$ -in. cell	Title and comments
			Total acid (as acetic)	Volatile acid (as acetic)	Esters (as ethyl acetate)	Fusel oil (as amyl alcohol)	Solids	Alde- hydes	Fur- fural	
51,599	84.4	..	14.4	7.2	21.1	73.9	18.4	4.0	None	12.0; caramel, no age
51,600	85.2	..	17.2	4.8	28.2	61.6	74.4	2.4	None	1.5; no artificial color
51,601	85.2	..	14.4	7.2	43.1	91.6	0.8	None	1.5; caramel, no age	
51,602	87.6	..	2.4	2.4	17.6	71.4	3.2	None	1.5; no artificial color	
51,605	86.4	..	9.6	4.8	44.9	94.2	9.4	0.2	None	1.5; no artificial color
51,608	84.6	5.32	14.4	14.4	22.9	94.2	17.6	0.6	None	13; caramel, no age
52,288	91.0	..	9.6	4.8	29.9	79.8	31.7	0.6	None	12; caramel, no age
52,289	89.6	..	9.6	4.8	14.9	28.2	66.6	None	None	1.5; caramel, no age
52,290	89.6	..	16.8	9.6	13.2	45.8	91.8	1.0	None	13.0; caramel, no age
53,543	97.6	..	24.0	21.6	20.2	58.1	76.7	None	None	1.5; no artificial color
53,544	88.4	5.67	21.6	7.2	12.3	61.6	162.4	None	None	14.0; caramel, no age
52,979	88.2	..	21.6	..	19.4	29	71.0	None	None	20; caramel, no age
52,980	88.8	..	38.4	..	29.9	87.1	10.6	None	None	3; no artificial color, age
52,981	89.6	..	7.2	4.8	17.6	37.8	43.0	0.4	None	1; no artificial color
53,147	88.3	..	4.8	4.8	11.4	58.1	40	1.6	0.4	1.0; no artificial color
54,257	87.4	5.09	14.4	9.6	15.8	59.8	35.4	3.2	0.6	13; caramel, no age
53,150	82.3	..	31.2	..	17.16	66.9	22.0	4.8	None	7.5; caramel, no age
36,039	87.3	5.03	13.2	12	11.4	49.3	67.8	1.6	0.1	14.5; caramel, no age
36,041	87.2	..	2.4	2.4	8.8	51.0	52.6	1.2	None	1.0; no artificial color
60,129	89.2	5.58	9.6	8.4	7.9	25.5	50.2	6	0	1.5; no artificial color
60,040	92.2	..	5.29	19.2	47.8	91.5	7.0	0	12; caramel, no age	Ron Anejo Vencedor; fair rum taste
60,047	92.8	..	5.54	12	12.0	15.8	91.5	6.2	0	1; no artificial color
60,049	89.8	..	5.34	14.4	12.0	54.6	78.0	7.7	0	1; no artificial color
60,050	87.6	..	5.14	19.2	16.0	15.8	34.8	7.0	Trace	7; caramel, no age
60,054	87.0	..	5.57	24.0	21.6	19.4	47.5	5.5	0	11; caramel, no age
60,057	93.6	5.63	12.0	12.0	17.6	29.9	72.5	4.6	0.32	3; caramel, no age
78,432	88	4.92	60	49.2	29.9	65.1	95.6	7.7	0.32	16.5; caramel, some age
										La Cabana (Havana); claims to be 16 years old

^a P. Valaer, *Ind. Eng. Chem.*, 29, 988 (1937).

TABLE 77
ANALYSES OF AUTHENTIC VIRGIN ISLAND RUMS^a

Lab. No. ^b	Proof	pH	G. per 100 liters			Color, 1/2-in. cell			Title and comments
			Total acids	Volatile acids	Esters	Fusel oil	Solids	Alde- hydes	
51,603	89	4.88	33.6	33.6	65.1	55.4	52	5.6	7; no artificial color
52,563	90.6	4.47	9.6	88.8	67.8	61.7	130	12	1.2
60,073	89.9	4.88	36	33.6	61.6	56.3	65	8.8	5; no artificial color
60,464	92.8	8.05	4.8	2.4	44.0	59.8	56	7.0	6.5; no artificial color
77,652	91.2	7.62	9.6	2.4	43.1	58.1	178	7.5	16.5; no artificial color
51,604	91.2	..	24	16.8	24.6	80.1	578	7.3	1.6; aged in new, heavily charred barrel
60,041	93.2	..	26.4	24.0	28.2	73.9	580	14.3	St. Croix; good rum taste
69,332	95.6	5.72	43.2	24	24.6	650	16.0	0	St. Thomas; good rum taste
69,445	91.8	4.54	69.6	57.2	57.2	17.6	156	16.0	St. Thomas; rum taste, contains neutral spirits and other added ingredients
76,462	106.4	6.48	21.6	8.4	11.4	21.2	1068	2.4	St. Thomas; rum taste, contains neutral spirits and added solid ingredients

^a P. Valaer, *Ind. Eng. Chem.*, **29**, 988 (1937).

^b Samples 51,603, 76,462, 69,332, and 60,041 contain added solid ingredients and coloring matter, and hence would be classed in U.S.A. as rectified products. Samples 77,652 and 71,652 are abnormally low in acids for 1.5-year-old rum; the alkali extracted from the heavily charred surface probably neutralized some of the acids formed.

^c Artificially colored with caramel.

TABLE 78
ANALYSES OF AUTHENTIC JAMAICA RUMS^a

Lab. No.	Proof	pH	G. per 100 liters (not calc. to proof)			Color, 1/2-in. cell			Title and comments
			Total acid	Volatile acid	Esters	Fusel oil	Solids	Alde- hydes	
55,291	98.4	..	36	24	63.3	99.3	260	16	1.6
55,292	99.8	..	76.8	60	95	99.8	880	14.4	2.8
63,149	90.4	..	48	38.4	75.7	88	478	6.4	72; heavy caramel and age color
64,380	90.6	..	48	38.4	105.6	62.5	316	0	10; caramel and age color
64,381	86	..	38.4	28.8	82.7	66.5	290	0	36; heavy caramel and age color
64,382	87.2	..	43.6	31.2	61.6	95	482	2.4	11; caramel, slight age
64,383	98.4	..	45.6	31.2	63.6	107.4	438	4	24; caramel, some age
60,042	98.6	3.85	88.8	50.4	89.8	89.76	884	20.0	1.2
60,044	86	4.44	52.8	48.0	64.5	70.4	305	Trace	5.0
60,060	98.6	4.17	57.6	48.0	59.8	91.52	450	20.0	13.0; caramel, some age
60,061	98.2	..	57.6	48.0	59.8	84.48	492	18.0	4.0
60,069	90.4	4.62	55.2	48.0	62.5	93.8	325	0	24.0; caramel, slight age
								3.2	10.0; caramel, slight age

^a P. Valaer, *Ind. Eng. Chem.*, **29**, 988 (1937).

TABLE 79
ANALYSIS OF RUMS MANUFACTURED IN THE UNITED STATES^a

Date taken	Lab. No.	Serial No.	pH	Proof	G. per 100 liters (not calc. to proof)						Color in cell	Approx. age and comments	
					Total acids (as acetic)	Volatile acids (as acetic)	Esters	Fusel oil	Solids	Aldehydes			
Run 1, Pennsylvania ^b													
4/1/35	54,907	327,335	4.66	103	16.8	9.6	16.7	123.0	28	4.4	0.6	2	New, percolated through chips
10/4/35	60,851		4.44	103	33.6	28.8	21.1	123.2	66	5.1	1.0	5	6 mo.
4/15/36	66,797		4.46	105.4	38.4	31.2	24.6	124.1	66	6.3	1.2	6	1 yr.
10/4/36	72,193		4.35	106.4	45.6	33.6	28.2	128.5	94	6.3	1.0	1.5 yr.	
3/29/37	76,726		4.30	108.8	52.8	39.6	32.6	126.7	106	6.6	1.0	7.5	2 yr.
4/1/35	54,908	327,820	4.76	103.0	9.6	9.6	16.7	123.2	8	4.4	0	0.2	New
10/4/35	60,852		4.54	103.6	33.6	26.4	23.8	124.3	48	4.7	Trace	4	6 mo.
4/15/36	66,796		4.52	104.8	36.0	28.8	26.4	124.0	50	5.5	0.8	1 yr.	
10/4/36	72,194		4.46	105.6	43.2	33.6	29.0	128.5	78	6.4	0.8	6.5	1.5 yr.
3/29/37	76,727		4.44	107.8	50.4	40.8	33.4	132.0	94	6.8	0.8	7.0	2 yr.
Run 2, Kentucky ^c													
3/24/35	55,215	69,689	4.28	102	14.4	14.4	43.1	102.1	16	40	5.5	0	New
10/2/35	60,798		4.33	102.2	69.6	52.8	47.5	103.4	136	40	8.2	11.0	0.5 yr.
5/23/36	68,497		4.17	104.4	80.4	67.2	60.7	108.6	168	40	8.2	13.5	1 yr.
9/23/36	72,890		4.13	104.8	84.0	67.2	65.1	117.1	184	40.1	10	16.5	1.5 yr.
3/23/27	76,714		4.28	106.8	88.8	73.2	73.0	116.2	204	34.3	12	17.0	2 yr.
3/25/35	55,216	69,690	4.20	101.2	14.4	14.4	36.9	102.6	12	40	6.3	0	New
10/2/35	60,799		4.20	101.6	62.4	52.8	47.5	107.4	126	40	7.5	9.0	0.5 yr.
3/25/36	66,437		4.25	103.6	69.6	62.4	51.0	110.9	140	40	7.5	11.5	1 yr.
9/23/36	72,891		4.13	105.2	76.8	62.4	56.3	117.9	168	42.3	10	14.0	1.5 yr.
3/22/27	76,715		4.30	107.2	81.6	68.4	64.2	119.7	182	37.0	12	14.0	2 yr.

TABLE 79 (Continued)

Date taken	Lab. No.	Serial No.	pH	Proof	G. per 100 liters (not calc. to proof)						Color in cell	Approx. age and comments	
					Total acids (as acetic)	Volatile acids (as acetic)	Esters	Fusel oil	Solids	Aldehydes			
Rum 3, Massachusetts ^a													
3/8/35	56,291	123,066	4.68	100.6	38.4	36.0	22	91.7	6	4.4	1.2	0	New
9/10/35	60,647	4.42	100.4	84.0	74.0	29.0	86	6.4	1.2	7.5	6 mo.		
9/16/36	71,652	4.37	101.4	93.4	86.4	45.5	93.3	142	7.2	1.4	11.0	1.5 yr.	
3/15/37	76,691	4.30	102.4	98.4	86.4	51.0	96.8	162	7.2	1.6	13.0	2 yr.	
3/8/35	56,292	123,067	4.44	100.6	38.4	36.0	21.1	91.3	6	4.4	1.2	0	New
9/10/35	60,648	4.42	100.6	84.0	69.6	29.9	91.5	88	6.4	1.3	7.5	6 mo.	
9/16/36	71,653	4.35	101.6	96.0	86.4	45.8	92.4	138	7.0	1.4	11.0	1.5 yr.	
3/15/37	76,692	4.30	102.4	98.4	85.2	49.3	100.3	156	7.4	1.8	13.0	2 yr.	
Rum 4, Massachusetts ^e													
9/26/35	60,649	8	4.43	97.8	91.2	84.0	34.3	196.4	80	5.0	1	3.5	1 yr.
5/30/36	68,285	4.43	95.4	88.8	79.2	34.3	204.2	142	5.2	0.8	8.0	1.5 yr.	
11/4/36	74,544	4.36	94.8	91.2	81.6	34.3	191.8	150	5.4	1.2	8.5	2 yr.	
3/1/37	76,737	4.35	94.8	91.2	85.2	38.7	191.8	176	6.4	1.2	10.0	2.5 yr.	
9/26/35	60,650	23	4.52	96.8	88.8	76.8	222.9	187.3	5.0	1.0	7.5	1 yr.	
5/30/36	68,286	4.33	97.6	93.6	81.6	44.9	198.9	104	5.5	1.2	6.0	1.5 yr.	
11/4/36	74,546	4.20	96.8	96.0	86.4	51.9	204.2	102	5.1	1.2	5.0	2 yr.	
3/1/37	76,738	4.20	96.8	96.0	86.4	55.4	212.9	110	5.9	1.2	6.0	2.5 yr.	
Rum 5, Massachusetts ^f													
6/13/35	58,256	540	5.23	103	4.8	48.0	21.1	98.6	12	7.0	3	0	New
12/13/35	64,571	4.40	102.4	48.0	48.0	22.9	98.6	92	7.5	5	7	6 mo.	
6/13/36	70,034	4.26	102.6	55.2	48.0	22.0	98.6	120	8.0	8	8	1 yr.	
12/11/36	74,548	4.30	102.4	64.8	52.8	25.5	98.8	128	8.4	6.5	9	1.5 yr.	
6/12/37	79,311	4.23	103.4	67.2	52.8	27.3	100.0	142	8.91	6.4	10.5	2 yr.	
6/11/35	58,257	570	5.28	102.8	4.8	4.8	18.5	98.6	12	6	4.8	0	New
12/17/35	64,572	4.40	102.8	48.0	48.0	22.9	98.6	84	7	5	7	6 mo.	
6/17/36	70,035	4.30	102.6	54.6	48.0	22.9	99.4	108	7.2	7.5	7.5	1 yr.	
12/17/36	74,549	4.33	102.8	60.0	55.2	25.5	100.3	114	7.4	6.0	8.5	1.5 yr.	
6/17/37	79,312	4.23	103.6	62.4	56.4	29.9	102.1	130	7.7	6.4	9.0	2 yr.	

Rum 6, Massachusetts^a

	24	4.48	103.4	67.2	55.2	35.2	174.2	156	7	1.5	10.5	1.5 yr.
9/27/35	60,659			4.38	104.8	74.4	55.2	40.5	176.0	9.6	1.4	11.0
3/27/36	67,301			4.39	105.0	74.4	64.8	39.6	178.0	9.0	1.0	13.0
9/25/36	72,147			4.42	106.2	72.0	62.4	42.2	179.8	7.3	1.2	14.0
3/25/37	76,984			4.42	104.4	67.2	40.8	33.4	176.7	164	1.0	10.5
9/27/35	60,660	66		4.35	105.6	69.6	43.2	36.9	182.5	176	1.2	11.0
3/27/36	67,302			4.37	105.8	72.0	57.6	38.7	185.4	188	1.0	13.0
9/25/36	72,148			4.33	107.2	72.0	61.2	40.5	196.4	190	1.2	2.5 yr.
3/25/37	76,985											3 yr.

^a P. Valaer, *Ind. Eng. Chem.*, **29**, 988 (1937).

b Barrel 327,335 made from Java molasses, 54.56% invert sugar, Brix 84.4. Ratio of mash, 4.5:1; 5003 gal. of molasses to make 27,352 gal. of beer. Yeast culture developed in a molasses medium for inoculation of a small molasses mash, this in turn used to develop larger yeast mashes. Beer column still used. Proof of distillation, 117°. Distillate percolated about 5 hrs. at 90° F. with toasted chips; approximately 1400 lbs. of chips used in a batch of 7935° proof gal. Cooperage re-used. Storage, brick building, steam heated; fan blowing hot air into circulation. Approx. winter temp., 70° F.; during summer months, heaters not used. No additional treatment in the warehouse. Barrel 327,320, all conditions same except the proof of distillation was 121° and there was no chip treatment.

c Rum from barrels 69,689 and 69,690 produced in a pot still, capacity 19,776 gal. Proof of distillation, 135°. (average); composition of mash, 6 parts water and 1 part blackstrap molasses, with pure yeast added. Bailing, 15°; sp. gr., 1.0613. No quick age or chips employed. Cooperage, new charred white oak barrels; warehouse brick with concrete floor. Temp. first year 85-90° F. (steam heat); after that, 70-72° F. Original wine gal., 48.5 and 47.28; original proof gal., 48.99 and 47.75, respectively.

d Rum distilled in continuous-type still; capacity, 6834 gal. of beer without doubler; rectifier used to keep up proof of spirits. Proof when distilled, 121°; reduced to 100° proof in cistern before being drawn off into bbls. No quick age applied to spirits before warehousing. Cooperage, new charred white oak barrels. Warehouse constructed of brick with wooden floors, steam heated in winter. Average temp. about 70° F. during year. Samples have fine rum flavor. Neither bbl. was sampled at the 1-yr. period through an oversight.

e Rum distilled in continuous-type still and rectifying column combined; capacity, 1250 wine gal. of 120° proof every 8 hrs. Original proof of rum, 145°. Processed by being passed through a basket of charred oak chips inside a percolating tank, and circulated by means of a pump through the chips for 10 min. Package 8 was newly charred; package 23 was re-used hbl. Warehouse heated, average yearly temp. 80° F. Heating system is a steam coil unit inside a humidifier, which sprays the bbls. with hot vapor; relative humidity 85%. Serial 8 produced 8/28/24, original proof 95°, serial 23 produced 8/29/34, original proof 96°. Esters developed faster in re-used than in newly charred barrel. f Molasses mash, distilled in pot still and doubler; working capacity of still, 1000 gal.; doubler capacity, 150 gal. Beer heater used. Charge of 1000 gallons is dropped from beer heater into still; at the same time the high and low wines (heads and tails) are dropped into the doubler. Proof of distillation, 153°. No quick aging. New charred white oak bbls. Normal humidity. Average temp. of warehouse 70° F. (steam heated).

g Rum distilled April 4, 1934. Continuous-unit still with capacity of 1200 gal. of beer an hr.; doubler capacity, 845 gal. Original proof 135°. No quick aging. Cooperage, new charred white oak. Package 24 originally contained 46.06 wine gal. and 46.52 proof gal.; package 66 originally contained 45.42 wine gal. and 45.87 proof gal. Warehouse of wood construction, average storage temp., 75° F.

Rum is any alcoholic distillate from the fermented juice of sugar cane, sugar-cane sirup, sugar-cane molasses, or other sugar-cane by-products, distilled at less than 190° proof (whether or not such proof is further reduced prior to bottling to less than 80° proof) in such a manner that the distillate possesses the taste, aroma, and characteristics generally attributed to rum, and includes mixtures solely of such distillates. "New England rum" is rum as defined above, except that it is produced in the United States, is distilled at less than 160° proof, and is a straight rum and not a mixture or blend. All the other rums mentioned above are not distinctive types; their names are not generic but retain their geographic significance. These names may not be applied to rum produced in any other place than the particular region indicated in the name.

The usual forms of adulteration which are not extensive, are using imitation flavor, misstating ages, or refilling one rum bottle with another brand or other material.

9. Other Types of Distilled Liquors

(a) *Okolehao*

Okolehao is a distillate produced in Hawaii. It was originally made by distilling, in a crude fashion, a fermented mash consisting principally of the ground or macerated ti root. Its broadest definition has become "any distilled liquor produced in Hawaii." A typical product is a distillate made in Hawaii from sugar or sugar-cane juice, malted rice, and grain (usually corn). It may be flavored with ti root either in the mash or added after distillation. The presence of ti root flavor should be indicated in the statement of composition. An often-used, simple okolehao formula is approximately as follows: molasses, koji rice, juice of the ti root, and water. The okolehao distillate is usually aged in charred oak barrels, the proof of entry being 80-90°. Its taste and aroma are usually those of newly distilled corn whisky.

(b) *Tequila and Mescal (Mezcal)*

Tequila and *mescal* are the most important distilled liquors intended for beverage use which are produced in Mexico, and have their sources in certain species of cactus plants which grow in great abundance in that country.

The production of tequila is fairly limited to the State Jalisco, which lies on the high and vast fertile central plateau of Mexico and whose principal city is Guadalajara, 381 miles northwest of Mexico City, to which it is second in size and importance. Around the small town of Tequila, about 30 miles north of Guadalajara, five or more tequila distilleries are located. In this vicinity, countless acres of cultivated cactus are grown. As many as 3,000,000 tequila cactus plants may be found in one area, growing in even, cultivated rows like corn. Mescal is produced to a large extent in the San Luis Potosi area, in Michoacan and Guanajuato in the central part of the republic, and in the states of Oaxaca and Guerrero which lie south of Mexico City.

Although tequila and mescal are often loosely referred to as "tequila," the source and method of production of each are different, and they are listed as separate items

among Mexico's exportations. They are similar in that they have the characteristic herbaceous weedlike taste and aroma which is more pronounced in mescal than tequila, the latter being more neutral, having been refined to some extent by redistillation. The plant from which tequila is derived requires seven or more years of cultivation, whereas that from which mescal is produced grows wild and receives no cultivation. Tequila, which costs four to five times as much as mescal in Mexico, because of the extra care used in its production, is generally considered a superior product. In Mexico, pulque sells for two to four cents per liter, mescal about 20 cents per liter, and tequila about \$1.25 per liter (approximately one quart).

TABLE 80
ANALYSES OF TEQUILA AND MESCAL (MEXICAN)

Lab. no.	Proof	G. per 100 liters						Color $\frac{1}{2}$ -in. cell (Lovibond)	Name ^a and source
		Total acids	Esters	Fusel oil	Solids	Aldehydes	Furfurals		
55483	94.6	79.2	73.2	93.3	10	0	0.14	Colorless	Vino tequila, blend of tequila and alcohol, Guadalajara, Mexico
55654	96.4	86.4	66.0	90.6	14	0.8	0.13	Colorless	Tequila (Sauza), Guadalajara, Mexico
55655	93.6	79.2	67.8	92.4	14	0.8	0.16	Colorless	Tequila (Sauza), Guadalajara, Mexico
54656	91.8	16.8	18.5	44.9	32	0.8	0.10	0.5	Mescal, Mier, Mexico
54657	91.4	19.2	19.4	46.8	32	0.8	0.10	0.5	Mescal and tequila blend—Mier, Mexico
22185	100.2	79.2	73.9	112.6	17	...	1.2	Colorless	Mescal (Mezcal), brandy style
36598	103.1	69.6	66.9	161.9	12	...	1.2	1.2	Mescal, imported in barrels for rebottling, Mexico
35720	92.9	26.4	...	51.0	549 (sugar)	...	...	Colorless	Tequila (Mariachi brand), Jalisco, Mexico D. F.
35721	96.5	63.6	...	25.2	Fixed acids	1.2	3.5 Caram- mel (slight brown)	3.5 Caram- mel (slight brown)	Tequila, City of Tequila, Jalisco, Mexico D. F. (TOG)
35560	86.0	75.6	...	77.4	60	...	1.2	Colorless	Mescal (San Martin) San Luis Potosi, Mexico
37714	106.8	82.8	88.1	62.4	102.1	22	...	1.5	Mescal (San Martin) San Luis Potosi, Mexico, (115 re-used cleaned barrels)

^a All the products have an herbaceous weedlike taste, quite different in character from other distilled liquors.

Contrary to the general impression, neither mescal or tequila is distilled to any extent from pulque (see page 737). Mescal is distilled from the fermented mash made from the cooked central head and heart portion of the mescal *Agave*, including its shredded pulpy portion and juice. Tequila is distilled from the fermented mash made from the roasted (cooked) central head and heart portion, including the shredded pulp and its juice, of *Agave tequilana*. About 2 gal. of juice are obtained from each cactus head. The macerated juicy mass is poured into large vats and adjusted with water to reduce the saccharine content to an approximate standard, and is yeasted. Some distilleries add sulfuric acid to invert the sugars and speed fermentation with ammonium sulfate. After fermentation, about a week or longer, both mescal and tequila mashes are distilled in simple pot stills (*alambique*) consisting of a distilling

chamber and a head attached to a water-cooled worm. The stills are steam or fire heated. Mescal is distilled in a single operation. Tequila is rectified to some extent by redistillation.

Both distilled products, tequila and mescal, are usually sold colorless and are not aged. Occasionally they are given a very pale amber color with caramel, or they may have taken on a pale amber color due to some storage in wood. As far as has been determined, both products always contain small amounts (0.10 to 0.17% by volume) of methanol, which serves to some extent to identify them. The general chemical character may be seen in the chart of analyses (Table 80).

The total exports of tequila in 1941 (a normal year) were 18,665 kilograms (valued at 35,387 pesos), 15,641 kilograms (having a value of 29,963 pesos) of which went to the United States. During this time, the exportation of mescal was relatively insignificant. At present (1944), the exportations of both products have increased very much.

The usual form of sophistication, when found, consists of diluting mescal with cane spirits and representing it as tequila, or diluting tequila with cane spirits and modifying its original taste with foreign matter.

(c) *Sotol*

Besides tequila and mescal, there is produced in Mexico to a much smaller extent a distilled beverage known as *sotol*. The plant from which the beverage is derived is a liliaceous yuccalike plant of the genus *Dasyliuron*, which grows in abundance on the dry rocky mesas or hillsides in Mexico and Texas. In producing the liquor, the outside leaves of the plant are trimmed off in the same manner as for tequila or mescal, and the remaining head is either roasted or boiled, during which process the starches present are converted into fermentable sugar. The shredded and macerated pulp is pressed free of its juices and the latter, adjusted to convenient Balling, is yeasted and fermented. After fermentation, it is distilled in simple pot stills into a colorless distillate of an unusual and characteristic taste, more nearly resembling mescal than any other liquor. It has been produced in Mexico for many years. In Texas, recently, the *sotol* plant has been processed in a modern and scientific manner in order to produce a maximum alcohol yield. The fermented mass is distilled in highly efficient stills into very pure alcohol. It produces 15 to 20 wine gal. of 190 proof alcohol from a metric ton of *sotol* heads.

(d) *Vodka*

Vodka is a distilled liquor originating in Russia but produced also in Poland and to a small extent in other bordering countries. The Russian product is almost completely without identifying characteristics except that of diluted alcohol. As far as can be determined, its principal source is wheat; it is certain that rye, barley, corn, and potatoes have at times also been used in its production. Its manufacture does not differ very materially from the production of other distilled liquors from cereal grain.

Malt is added to the cooked cereal mash to convert the starches to fermentable sugar in the usual way and the resulting fermented beer is distilled in column stills, with considerable rectification, into pure or almost pure neutral spirits. The distillate is reduced usually to about 100° proof. Sometimes the proof may range from 90° to 120°. See Table 81.

It is apparently the purpose of the Russian vodka distillers and some domestic producers to obtain a product as tasteless and odorless as possible. To this end, the distillate, which is practically neutral spirits, is often filtered through charcoal or activated carbon for the purpose of producing, if possible, a product with still less identifying characteristics.

TABLE 81
ANALYSIS OF VODKA AND NEUTRAL SPIRITS FOR COMPARISON

No.	Proof	G. per 100 liters					Character of sample
		Acids (as acetic)	Esters	Fusel oil	Solids	Methanol	
1	100	4.0	5.7	1.8	8.0	None	Vodka made in U. S. from neutral spirits through charcoal
2	100	1.2	3.1	1.8	3.0	None	Diluted neutral grain spirits
3	112	1.6	5.5	4.5	8.0	Trace	Vodka produced in U. S. S. R.
4	100	1.2	5.8	1.8	4.0	Trace	Vodka produced in Lwow, Poland
5	100	1.0	4.0	1.0	11.0	Trace	Vodka produced in Warsaw, Poland
6	100	1.2	5.5	3.5	2.0	None	Chemically pure alcohol diluted to proof

Some producers in Russia, Poland, and the United States make vodka in the simplest possible manner by diluting neutral spirits and filtering it through charcoal or activated carbon. The solids of vodka produced in this manner usually have an alkaline reaction. Vodka is always sold colorless and is not aged. There are several modifications (in which herbs and other ingredients are added) given other Russian and Polish designations, which are not important commercially. In the United States, the only producers of vodka are rectifiers who endeavor to purify neutral spirits further with activated carbon (or charcoal) or merely add to diluted neutral spirits very small amounts of flavoring ingredients.

(e) *Sliwowitz*

*Sliwowitz*¹⁰ is the name given to fresh plum brandy originating in Yugoslavia. Other important places of production are Rumania, Slovakia, Hungary and, in general, the foothills of the Carpathians where plums are plentiful. The name is now generally applied to any brandy distilled from plums.

The process of producing sliwowitz is as follows: The whole ripe fruit is ground with about one-third of the pits. Because of the addition of the ground pits, there is introduced a small amount of hydrocyanic acid and therefore a characteristic bitter

almond taste. It is claimed that only 0.008% of hydrocyanic acid is found in the finished distilled sliwowitz. After grinding, the plum mash is yeasted with a pure yeast culture and placed in tanks for fermentation. The tanks are large, reinforced, and glass-lined, and are often of 100 or more tons capacity and usually located underground. After fermentation, the fermented plum mash is distilled, in continuous stills in some instances, and if the distillery is small, in pot stills equipped with agitators having direct heating. The heads and tails are usually removed for treatment and separate distillation. Aging or storing is conducted in large wooden vats or in new, treated Slavonian oak barrels.

(f) *Kirschwasser*

Kirschwasser is a distillate from a cherry mash and is the principal local beverage of a small region of central Europe including Alsace, the Black Forest region of Germany, and a few cantons of northern Switzerland. The mash is made of a small black cherry (without crushing the pits in Germany and Switzerland, and with crushing them in Alsace) which grows in this region. It is distilled in pot stills, by the growers, and by a few commercial distillers, into the colorless and highly aromatic spirit, *kirschwasser*. *Kirschwasser* is consumed at relatively high proof and almost without aging. During the fermentation of the cherries, it is believed that some of the bitter principles, including amygdalin, are dissolved from the cherry stones if the pits or stones are crushed, and even to a slight extent when they are unbroken. The bitter, almondlike oil and other substances, including traces of prussic acid, give this type of cherry brandy its principal characteristic taste and aroma.

Kirschwasser is a comparatively expensive spirit. It is sometimes adulterated by blending with the cheaper prune distillate (*Zwetschgenwasser*), with alcohol, or with a mixture of bitter almond oil in alcoholic solution.

Kirschwasser is produced in other parts of Europe and, more recently, has been made in the United States; but these products do not appear to be quite the same as that originally imported, probably because the cherries from which it is distilled are not the same variety of fruit. The American product is made principally in Oregon.

(g) *Bitters*

Bitters fall into two general classes—medicinal bitters and aromatic flavoring bitters. They are divided for tax purposes into two classes—those which are susceptible of beverage use and incur the internal revenue and State taxes and must be sold and stamped under the same conditions as intoxicating liquors, and those which are unfit for beverage use and are exempt from internal revenue tax.

Medicinal bitters, to be classed as unfit for beverage use and exempt from internal revenue tax, must contain in each ounce of finished product at least two U. S. P. or N. F. doses of drugs of recognized therapeutic value and such other ingredients as will render the product insusceptible of beverage use.

Aromatic or flavoring bitters must be strong infusions of herbs with aromatics and oils in sufficient quantities to render the product unfit for use as a beverage.

V. DENATURED ALCOHOL AND DENATURED RUM¹¹

Denatured alcohol is ethyl alcohol to which have been added materials which render it unfit for beverage use. It is tax-free and is used directly or indirectly in the production of thousands of articles which are part of our daily life. Because of the war, statistics relating to the production and use of denatured alcohol are not being released. Table 82, however, lists the products manufactured with specially denatured alcohol during the fiscal year ended June 30, 1940, and illustrates how essential industrial alcohol is to industry in this country.

Before the Act of June 7, 1906, all alcohol was taxed; consequently its industrial applications were limited by its cost. This law, which made it possible to obtain alcohol free of tax for industrial use, has been amended and new laws enacted so that ethyl alcohol or distilled spirits of 160° proof or more, and rum of not less than 150° proof, may now be produced and withdrawn free of tax for industrial purposes after denaturation, in accordance with formulas authorized by the Commissioner of Internal Revenue with the approval of the Secretary of the Treasury.

Ethyl alcohol, or distilled spirits, may be denatured only in a denaturing plant operating under a permit issued by the Alcohol Tax Unit, Bureau of Internal Revenue. Rum must be denatured in a denaturing bonded warehouse approved by the Commissioner of Internal Revenue. At the present time there are three classes or kinds of denatured alcohol—completely denatured alcohol, specially denatured alcohol, and denatured rum.

1. Completely Denatured Alcohol

Completely denatured alcohol is ethyl alcohol to which have been added certain specified materials which are of such character and composition that they cannot be readily removed from the alcohol by distillation, by extraction with solvents, or by dilution with water. This kind of denatured alcohol may be freely sold and used without a federal permit or license, but records of sale must be kept by producers. Dealers and manufacturers receiving, storing, selling, or using 11 drums (550 wine gal.) per month must keep records showing the receipt and disposition of the alcohol. Manufacturers recovering completely denatured alcohol in any process must obtain a permit and give bond covering the operation. Containers holding more than 5 wine gal. must be of steel, bearing embossed serial numbers and identifying symbols, in order that they may be traced and identified if the alcohol is diverted for illegal purposes.

Over 50,000,000 wine gal. of completely denatured alcohol were produced and used yearly in 1926 and 1927. Synthetic methyl alcohol, isopropyl alcohol, and glycols have been gradually replacing completely denatured alcohol for solvent and antifreeze purposes, resulting in a gradual reduction of its annual consumption to approximately 20,000,000 gal. by 1940.

¹¹ The section on denatured alcohol was written by Mr. William V. Linder, Chief, Laboratory Division, Alcohol Tax Unit, Bureau of Internal Revenue.

TABLE 82

STATISTICS ON THE USES OF SPECIALLY DENATURED ALCOHOL^a, BY KINDS OF PRODUCTS OR USES,
FISCAL YEAR ENDED JUNE 30, 1940

Product or use	Number of permittees	Wine gal.		
		Amount used		Amount recovered for re-use
		New	Re-used ^b	
CELLULOSE, RESIN, AND RELATED PRODUCTS:				
Lacquers, varnishes, and enamels:				
Cellulose	72	1,438,752	1,720,887	1,759,700
Synthetic resins (with or without natural resins but containing no cellulose compounds)	24	103,775	175	.....
Shellac (containing no cellulose or synthetic resins)	384	3,773,291	638	545
Other natural resins (containing no cellulose, synthetic resin, or shellac)	94	1,243,089	.....	.....
Candy glazes	27	63,342	.....	.....
Other coatings	36	58,350	.....	.....
Total lacquers, varnishes, and enamels	502 ^c	6,685,599	1,721,700	1,760,245
Plastics:				
Cellulose compounds	12	994,337	617,012	835,725
All other plastics (containing no cellulose)	22	1,782,813	683,219	672,601
Total plastics	32 ^c	2,776,950	1,300,231	1,508,326
Photographic film (including emulsions)	41	279,657	1,562,472	1,414,490
Transparent sheeting	7	30,664	534,357	539,694
Cellulose intermediates	5	257,450	189,233	202,893
Explosives	2	1,034,602	2,358,887	2,357,520
Polishes	36	172,993	.....	.....
Adhesives	38	79,960	.....	.....
Soldering flux	64	132,271	.....	.....
Inks, stains, and dye solutions (containing no cellulose or resins)	109	128,975	30	.....
Total cellulose, resin, and related products	731 ^c	11,579,121	7,666,960	7,783,168
SOLVENTS AND THINNERS FOR CELLULOSE, SHELLAC, RESIN PRODUCTS, ETC.:				
Proprietary solvents	31	16,803,735	.....	.....
Other industrial thinners	69	994,734	5,086	.....
Total solvents and thinners	93 ^c	17,798,469	5,086	.....
TOILET PREPARATIONS:				
Hair and scalp preparations	848	1,084,980	1,569	1,511
Shampoos	170	224,821	.....	.....
Bay rum	301	262,997	.....	.....
Face and hand lotions	716	629,571	.....	.....
Body deodorants	63	14,995	.....	.....
Toilet waters	550	1,050,652	.....	.....
Perfume and perfume tinctures	404	198,856	.....	.....
Toilet soaps (including shaving cream)	88	40,293	.....	.....
Mouth washes	344	823,431	.....	.....
Tooth cleaning preparations	56	118,659	.....	.....
Total toilet preparations	1583 ^c	4,449,255	1,569	1,511
PROCESSING INDUSTRIAL, FOOD, DRUG, AND OTHER PRODUCTS:				
Nitrocellulose (dehydration of)	7	2,674,180	12,896,039	12,793,575
Sodium hydrosulfite	4	223,505	1,645,980	1,602,422
Wood rosin and synthetic resins	2	371,277	5,083,480	5,088,305
Petroleum oils	8	288,360	3,461,708	3,466,546
Pectin	6	91,133	3,256,344	3,257,957
Food products other than pectin	13	12,943	25,985	26,476
Drug products:				
Drug extracts	51	137,682	593,154	615,147
Glandular products and vitamins	42	429,047	5,096,217	5,023,951
Medicinal chemicals	51	442,316	690,971	737,565
Miscellaneous (including pill and tablet manufacture)	98	65,341	108,271	141,489
Dyes and intermediates	14	786,107	268,105	444,510
Perfume materials and fixatives	11	49,217	217,164	217,677
Photographic developers	5	80,199	99,327	99,404
Other chemicals	33	610,689	2,431,065	2,412,046
Miscellaneous	25	88,397	149,658	148,846
Total processing industrial, food, drug, and other products	238 ^c	6,350,393	36,023,488	36,075,916

TABLE 82 (Continued)

Product or use	Number of per- mittees	Wine gal.		
		Amount used		Amount recovered for re-use
		New	Re-used ^b	
PHARMACEUTICAL PRODUCTS FOR EXTERNAL USE:				
Rubbing alcohol	312	3,064,903	.....	.....
U. S. P. and N. F. preparations:				
Witch hazel	2	149,374	.....	.....
Liniments	114	87,243	.....	.....
Collodions	4	53,574	.....	.....
Antiseptics	56	17,534	.....	.....
Miscellaneous	1	136	.....	.....
<i>Total U. S. P. and N. F. preparations</i>	134 ^c	312,861	.....	.....
Tinctures of iodine (official and nonofficial)	36	83,024	.....	.....
Other preparations not U. S. P. or N. F.	528	283,984	235	234
<i>Total pharmaceutical products</i>	770 ^c	3,744,772	235	234
CLEANING, PRESERVING, AND FLAVORING PREPARATIONS:				
Tobacco sprays and flavors	106	1,774,564	.....	.....
Cleaning preparations (including cleaning operations)	272	240,332	8,378	16,794
Deodorant sprays (nonbody)	46	53,042	.....	.....
Disinfectants, insecticides, etc.	106	41,060	190,304	191,415
Sterilizing and preserving solutions	62	43,370	.....	422
Embalming fluids and related products	38	30,555	13	.....
Industrial soaps	11	15,627	2,433	.....
Photoengraving and rotogravure use	46	48,935	.....	.....
Miscellaneous	33	68,606	.....	.....
<i>Total cleaning, preserving, and flavoring preparations</i>	756 ^c	2,316,091	201,128	208,631
CONVERTED AS A RAW MATERIAL IN CHEMICAL MANUFACTURING:				
Vinegar and acetic acid	59	7,718,558	.....	.....
Ethyl acetate	11	6,670,130	672,864	591,786
Ethyl chloride	6	11,957,023	128,009	.....
Other ethyl esters	44	759,746	243,947	350,932
Dyes and intermediates	5	34,479	34,947	7,948
Acetaldehyde	4	24,572,238	16,558,493	16,577,098
Ether, ethyl	4	505,850	196,810	196,810
Ethers, glycol and other	5	899,303	7,448,804	7,449,054
Ethylene dibromide	4	2,140,021	197,480	197,480
Xanthates	5	570,598	.....	.....
Fulminate of mercury	5	152,952	17,344	17,628
Ethylene gas	7	1,084,573	.....	.....
Miscellaneous	22	716,103	108,227	111,999
<i>Total converted in chemical manufacturing</i>	119 ^c	57,781,574	25,606,925	25,500,730
FLUID USES:				
Antifreeze	12	3,861,154	.....	.....
Brake fluids	8	61,363	.....	.....
Cutting oils	3	14,665	.....	.....
Other fluid uses (including door checks)	59	57,394	39	.....
<i>Total fluid uses</i>	81 ^c	3,994,576	39	.....
FUEL USES:				
Motor fuels	5	39,946	.....	.....
Other fuel uses	7	82,429	.....	.....
<i>Total fuel uses</i>	12 ^c	122,375	.....	.....
LABORATORY AND EXPERIMENTAL USES	1343	228,007	6,130	8,990
GRAND TOTAL	4282 ^d	108,364,633 ^e	69,511,540 ^e	69,579,180 ^e

^a Includes specially denatured rum. [For these summaries, a primary classification has been adopted for specially denatured alcohol according to the basic functions it performs. The principal functions are: first, its use as a solvent; second, its use as a raw material in the production of other chemicals; and, third, its use as a fluid where it neither exercises a solvent action nor enters into a chemical reaction. In addition, small quantities are used as fuels. In the secondary classification, which is according to products, some products appear more than once. This occurs where alcohol is required to perform two or more functions. For example, dyes are listed under three headings since alcohol is employed as a raw material to produce a dye chemical, as a solvent to purify dyes, and as a solvent to produce a dye solution for the trade. In a number of processes, some of the alcohol can be recovered and used again. The table shows separately the amount of new specially denatured alcohol used and the amount of recovered specially denatured alcohol used.] ^b Represents amounts re-used after recovery from processes where the alcohol has not become a part of the finished product. Such alcohol may have been recovered during the fiscal year 1940 or prior thereto and from any of the listed processes. ^c Represents number of permittees within each major grouping. ^d Represents actual number of permittees operating. ^e Differences between these figures and totals published in *Statistics on Alcohol* for the fiscal year, 1940, are accounted for by delinquent and amended reports.

Because of the character of the denaturants used in completely denatured alcohol, it is not suitable for many manufacturing operations, and over 95% is being used for antifreeze purposes. A small quantity is used in extracting crude products and other processes in which the denaturants do not contaminate or interfere with the finished products. When completely denatured alcohol was denatured with wood alcohol, it was used extensively for cutting shellac and for other solvent purposes, but the use of wood alcohol in completely denatured alcohol was discontinued during Prohibition because of deaths reported to have been caused by its use by derelicts as a beverage.

At the present time there are three formulas (bearing numbers 12, 13, and 14) authorized for completely denatured alcohol, as follows:¹²

FORMULA No. 12

To every 100 gal. of ethyl alcohol of not less than 160° proof add:

- 4.0 gal. ST-115 or a compound similar thereto
- 1.0 gal. Dehydrol-O or a compound similar thereto
- 0.5 gal. acetaldol (hydroxybutyraldehyde)
- or 1.5 gal. methyl isobutyl ketone
- 1.0 gal. of kerosene

FORMULA No. 13

To every 100 gal. of ethyl alcohol of not less than 160° proof add:

- 4.0 gal. ST-115 or a compound similar thereto
- 1.5 gal. methyl isobutyl ketone
- 0.25 gal. acetaldol (hydroxybutyraldehyde)
- 1.0 gal. kerosene

FORMULA No. 14

To every 100 gal. of ethyl alcohol of not less than 160° proof add:

- 3.0 gal. Dehydrol-O or a compound similar thereto
- 1.75 gal. methyl isobutyl ketone
- 1.5 gal. kerosene

Kerosene, methyl isobutyl ketone, and acetaldol (hydroxybutyraldehyde) are well-defined compounds requiring no explanation or description. ST-115 is a trade name for a product containing no wood alcohol which is produced by the destructive distillation of wood; it contains acetone, methyl esters, pyrolytic bodies, and other complex compounds which are present in a crude distillate obtained by the destructive distillation of wood. Dehydrol-O is a trade name of a product obtained as a by-product in a synthetic process using hydrogen and other gases; it is a mixture of higher aliphatic, branched-chain primary and secondary compounds having a disagreeable odor and taste. The denaturants used in completely denatured alcohol are intended to impart a certain amount of unpleasant odor and a very disagreeable and nauseating taste. The use of compounds of complex composition with other compounds of known composition in denaturing alcohol renders it more difficult to convert into bev-

¹² Appendix to Regulations No. 3, containing the formulas for completely and specially denatured alcohol, may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at ten cents per copy.

erage spirits by distillation and other treatments intended to remove the denaturants from the alcohol.

2. Specially Denatured Alcohol

Specially denatured alcohol is ethyl alcohol to which have been added certain specified drugs, essential oils, chemicals, etc., which render the alcohol unfit for beverage purposes but do not interfere with its use in the manufacture of drugs, chemicals, and food products. Specially denatured alcohol formulas are authorized for special or definite processes or products. Therefore, a large number of different formulas are required to manufacture the thousands of articles produced from or with ethyl alcohol. In order to provide alcohol suitably denatured for the manufacture of these products, 56 specially denatured alcohol formulas have been authorized. They are numbered from 1 to 47; some bear the same number but are differentiated by letters, as, for example, 39-A, 39-B, 39-C, and 39-D.

In several instances the alcohol is denatured with the product to be manufactured from or with the alcohol. For example, specially denatured alcohol formula No. 18, authorized for the manufacture of vinegar, is denatured with vinegar. Formula No. 18-A, authorized for the manufacture of ether, is denatured with ethyl ether. Specially denatured alcohol formulas authorized for use in the manufacture of external pharmaceutical products are denatured with essential oils and medicaments which are the chief medicinal ingredients of the finished products. Specially denatured alcohol formula Nos. 25 and 25-A, authorized for the manufacture of U. S. P. Tincture of Iodine and other official iodine preparations, are denatured with iodine and potassium or sodium iodide.

Ethyl alcohol intended for use in the manufacture of ethyl acetate and other ethyl esters

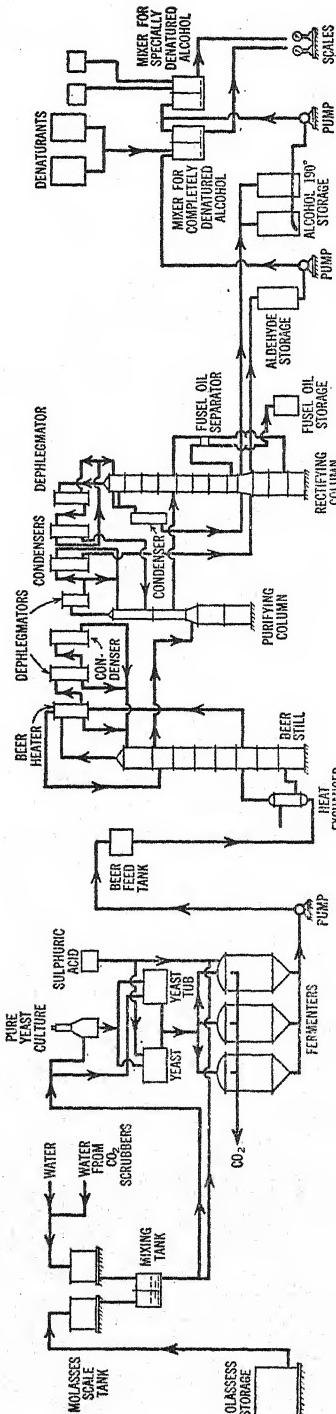


Fig. 157.—Flowsheet on modern molasses distillery.¹³

¹³ G. T. Reich, "Design of a Modern Molasses Dis-

is denatured with benzol, which does not interfere or contaminate the esters or other chemicals produced from this alcohol. Ethyl alcohol intended for use in the manufacture of perfumes, toilet waters, hair tonics, lotions, and other cosmetics must be, and is, denatured with odorless and nonirritating compounds such as quinine, brucine, sucrose octa-acetate, etc., which have a bitter or disagreeable taste but do not affect the odor of the finished products. It is obvious that these preparations could not be manufactured with alcohol denatured with odorous and irritating materials.

Specially denatured alcohol may not be used in manufacturing food products, flavoring extracts, and internal medicinal preparations if the finished products contain any of the alcohol used in their manufacture. Such products must be manufactured with tax-paid pure alcohol.

Since specially denatured alcohol formulas are authorized for specific purposes and in some cases do not contain denaturants which are difficult to remove, a permit and bond are required for their use. In applications made by prospective manufacturers or users the manner of use and purpose for which the alcohol is to be used must be stated. A bond must be furnished to cover the tax on the alcohol should it be diverted for illegal purposes, the penal sum of the bond being governed by the quantity of alcohol purchased and used per month. Applicants for permits to purchase and use specially denatured alcohol must submit their processes and formulas for the finished products to the Alcohol Tax Unit for review and approval before the permits are issued.

3. Denatured Rum

Denatured rum is rum of not less than 150° proof containing in every 100 wine gal. 1 gal. of an aqueous solution of nicotine and methylene blue. It is used almost exclusively for flavoring tobacco and may be obtained only under a permit in the same manner as specially denatured alcohol.

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Chapter XXV

INDUSTRIAL WATERS

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All natural water supplies contain impurities. These impurities may be visible or invisible. Thus color, sediment, and turbidity are visible while dissolved mineral salts are invisible. Organic growths, if present in large quantities as, for instance, clumps of algae or *Crenothrix*, are visible. On the other hand, a water, which is perfectly clear to the naked eye, may contain quantities of bacteria.

Whether or not these impurities are harmful depends on their nature, the amounts present, and the uses to which the water is to be put. Several hundred parts per million of calcium and magnesium salts, for instance, may be unobjectionable in a drinking water, highly desirable in beer or ale, highly objectionable in a cannery, and exceedingly harmful in a boiler feedwater. Other impurities, even when present in very small amounts, may make a water objectionable for practically all purposes. Iron or manganese, for instance, if present in amounts of only a few tenths of a part per million, will discolor or stain everything with which the water comes in contact and may promote the growth of iron or manganese bacteria, popularly lumped together as *Crenothrix*, in clogging amounts in pipe lines, recirculating systems, cooling jackets, etc. Hydrogen sulfide likewise is objectionable for all purposes even when present in only very small amounts. Less than one part per million imparts its characteristic, offensive, rotten-egg odor to the water, and even smaller amounts are corrosive to practically all metals. Therefore, in waters containing this undesirable component, complete removal is required regardless of the uses to which the waters are to be put. A host of other substances produce undesirable odors and tastes. The effects of some of these are so intense that as little as only a few parts per billion may be objectionable.

I. WATER TREATMENTS

If these or other impurities are present in harmful amounts, the water should be treated to remove them or reduce them to allowable limits. This may involve treatment of all the water, treatment of part of the water and/or different treatments of portions of the water according to the requirements of their end uses. In considering water treatment, it is convenient to take into account the forms of treatment used to

clarify turbid and colored waters, and the forms of treatment required for a water which is naturally clear or which has become so through treatment.

Both sediment and suspended matter, usually known as turbidity, are objectionable for such obvious reasons that it is unnecessary to detail them. Sediment is the term usually applied to the relatively coarse and easily settleable mud, sand, or silt found in water. Turbidity and suspended matter are the terms usually applied to the finely divided, semicolloidal, or colloidal matter found in water. Frequently, however, no differentiation is drawn between sediment and suspended matter and the two are measured together as turbidity. Sediment and turbidity are common in surface waters, while deep wells are usually free of them. In the case of rapidly flowing streams, the sediment and turbidity vary greatly with the seasons and the amount of rainfall, frequently changing manifold in only a few hours. In the case of large ponds, lakes, or reservoirs, the water may be relatively free from turbidity for the greater part of the time, but after a storm or at times of the spring or fall turnovers (due to temperature changes), such waters may become very turbid.

The organic impurities found in water supplies consist of soluble or colloidal matter derived from decaying organic matter and usually evident as color and as living and dead organisms. Organic impurities are commonly found in surface waters and are usually either absent or low in amount in ground waters; waters originating in swampy areas are usually highly colored, and in such cases, iron and/or manganese are also frequently present either in an organic or a colloidal form. Organic growths are common in surface waters and in waters, whatever their origin, which have been stored in open reservoirs: Some of these may be troublesome only in the warm summer months and may practically disappear during the rest of the year; others may be more or less troublesome at all seasons. Briefly, algae grow in relatively quiescent waters exposed to sunlight. Copper sulfate and chlorine are used to kill them, and covered reservoirs are frequently provided to discourage their growth.

Chlorination is the most effective method of killing bacteria. It may be carried out with liquid chlorine, chloramines, or hypochlorites. Furthermore, it may be applied before other treatments (prechlorination), after other treatments (post-chlorination), or both before and after.

1. Clarification Processes

(a) *Sedimentation*

If the water supply is drawn from a swiftly flowing river containing large amounts of coarse, easily settled sediment, sedimentation before coagulation often will result in savings of coagulant. Sedimentation may be accomplished in sedimentation basins, tanks, or reservoirs. If basins or tanks are employed, they should be designed so that the velocity of the water through them is low, and they should be baffled so as to prevent short circuiting. A means for removing the accumulations of sediment also should be provided. Sedimentation does not accomplish a thorough clarification of the water and, therefore, is to be regarded simply as a preliminary treatment for

waters of the nature described. For thorough clarification, coagulation followed by settling and filtration is usually required.

(b) *Coagulation and Settling*

Coagulation is practiced for the removal of both turbidity and color. It consists of adding to the water a substance, known as a coagulant, which reacts either with the natural alkalinity of the water or with added alkalinity to produce a gelatinous precipitate which enmeshes or adsorbs the turbidity or color, producing larger aggregations known as the "floc," which may then be removed by settling and filtration.

The most widely used coagulant is aluminum sulfate, commonly, though erroneously, called "filter alum." For efficient coagulation, it is necessary to maintain the ρH value of the water within a certain range. Broadly, aluminum sulfate coagulates well between ρH values ranging from about 5 to 7. The optimum ρH value for each surface water supply is best determined locally. The waters that coagulate most readily are those which consistently show an appreciable amount of turbidity and also contain appreciable amounts of dissolved mineral matter. Waters high in color and low in turbidity and dissolved mineral matter are the ones which are most difficult to coagulate.

In addition to maintaining the correct range of ρH values, mechanical agitation properly carried out is of great importance in forming a tough and easily settled floc. Variable speed agitators are of value in this connection, as their use enables adjustment of speed of agitation to obtain the best flocculation under all conditions. Correct agitation also broadens the range of ρH values under which good coagulation may be obtained, and effects notable savings in the amounts of chemicals used. In the case of waters having high color, low turbidity, and low dissolved mineral contents, the addition of clay has been found very effective in producing good coagulation and an easily settled floc. Clays vary in value for this purpose; also, the clay should not be too finely powdered.

Chemical Feeds.—In this connection, the value of reliable chemical feeding equipment cannot be overstressed. The time-honored device of hanging a bag of alum at the entrance end of the settling basin cannot be recommended because it is haphazard in feeding, rarely effects even an approximately good coagulation, and is extremely wasteful of chemical. Instead, a chemical feed which adds accurately measured and easily adjusted dosages of chemicals should be employed. Various types of chemical feeds are employed. These may be divided into the broad classifications—wet feeds and dry feeds. Typical wet feeds are shown in Fig. 158. Chemical feeds are further classified as constant feed or proportionating feed types. The former are employed when the flow of water to be treated is at a constant rate and this type of feed is connected so that the feeding of the chemical starts and stops simultaneously with the starting and stopping of the flow of water. The proportionating type of feed is employed when the flow of water to be treated varies, the feeding of the chemical varying proportionately with the flow rates of the raw water.

Settling Tanks and Basins.—Precipitators, floc formers, and settling tanks are employed for two purposes: for allowing a detention period sufficient to permit coagulation reactions to go to completion with the formation of a large, tough floc; and for settling out the bulk of the floc, thus relieving the load on the filters and per-

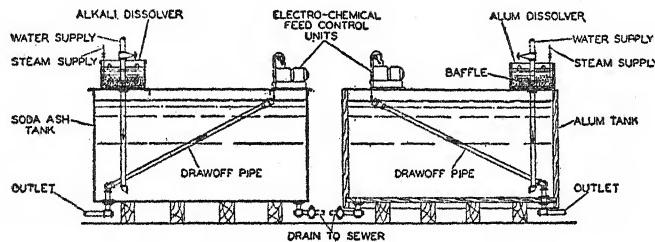


Fig. 158.—Typical wet alkali and alum feeds.
(Figs. 158-166 courtesy of Permutit Co., New York, N. Y.)

mitting much longer filtration runs between backwashings. Settling tanks or basins represent the older type of equipment, while the floc formers and precipitators represent later developments. Settling tanks, made of wood or steel, are usually above ground level. Settling basins, made of concrete, are usually partly or wholly below ground level. In designing these, use is made of baffles for directing a slow flow of the water through them and thus avoid short circuiting.

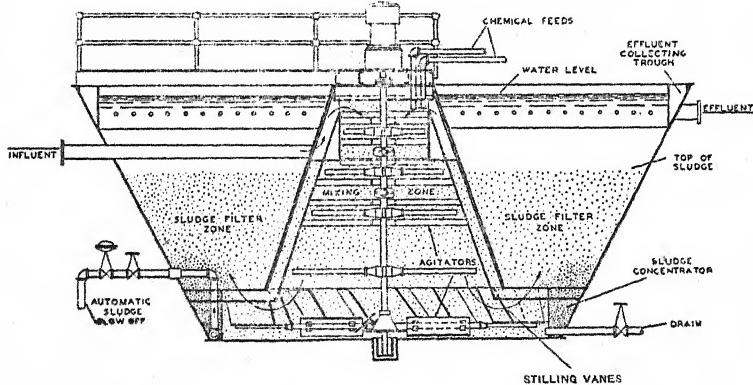


Fig. 159.—Precipitation type of coagulation and settling basin.

Precipitators.—The latest type of coagulating and settling equipment is represented by the precipitator¹ as illustrated in Fig. 159. In this, the raw water enters a central mixing section where the chemical is introduced and mixed with the water. A large, tough floc is produced by controlled agitation as the water passes downward

¹ E. Nordell, *Paper Trade J.*, 112, No. 18, 37 (1941).

through the device. Emerging through ports in the bottom of this inner section, the water then rises and is settled and filtered through a predetermined depth of previously formed sludge in the outer section, which is so designed that the cross-sectional area increases steadily from bottom to top. The increasing cross-sectional area results in decreasing steadily the vertical velocity of the water as it rises from the bottom to the drawoff trough in the upper part of the chamber. This decreasing upward velocity results in the water's reaching a plane at which its velocity is so low that it leaves the sludge behind; in practice, this is found to constitute a clean line of demarcation between the sludge and the settled water.

(c) *Filtering*

Sand filters usually are employed following the coagulation and settling processes. Their function is to remove any insoluble material, which has not settled out of the coagulated and settled water, and thus furnish a clear, clean, bright and colorless effluent.

The filter medium most widely employed is sand, hence the name sand filter. During the last decade, however, crushed and graded anthracite has come into favor as a filter medium. Filters may be divided into two classifications—the pressure type and the gravity type. In the pressure type, the container for the filter media is a closed steel shell designed for whatever pressures are required (Fig. 160). In the gravity type, the container for the filter media is an open concrete, wood, or steel shell (Fig. 161).

Whichever type is employed, the filter is equipped at the bottom with an underdrain system which serves the double purpose of acting as a collector for the filtered water on the filter run and as a distributor for the backwash water when the filter unit is cleansed by backwashing. Over this underdrain system lie several layers of graded gravel, the coarsest at the bottom and the finest at the top, then a layer of coarse sand and on this a layer of fine sand. During filtration, the water enters the upper part of the filter over a baffle, trough, or other design of distributor, passes slowly down through the layer of fine filter sand, then the coarse sand and supporting layers of gravel and into the underdrain system from which it flows to service. The filtration action is performed on the surface and in the upper layers of fine filter sand.

As filtration proceeds, the layer of coagulated matter which collects in the filter grows thicker and, as it does so, exerts an increasing resistance to the flow of water through it. This resistance is shown by pressure gages on the inlet and outlet of the filter; when this pressure differential, in the pressure-type filter, reaches some 4 to 5 lbs. per sq. in., the unit is cut out of service and backwashed. In gravity-type filters, a lower pressure differential indicates when backwashing is necessary.

Backwashing is performed by sending a strong stream of water through the underdrain system, upwardly through the gravel and sand layers, and out to the drain. This upward flow expands the filter bed, cleanses the sand granules, and washes the accumulated foreign matter up and out of the filter bed to the drain. Backwashing

should be performed at a flow rate of not less than 10 g.p.m. per sq. ft. of filter area and flow rates from 50 to 100% higher are often employed. A new development in cleansing filters is a rotating surface washer which thoroughly scours the surface of the filter bed. Backwashing usually is carried out for about 10 min. After backwashing, the filter unit is then rinsed to waste for a few minutes so as to settle the bed and build up a small layer of coagulated matter on and in the upper layers of the filter sand.

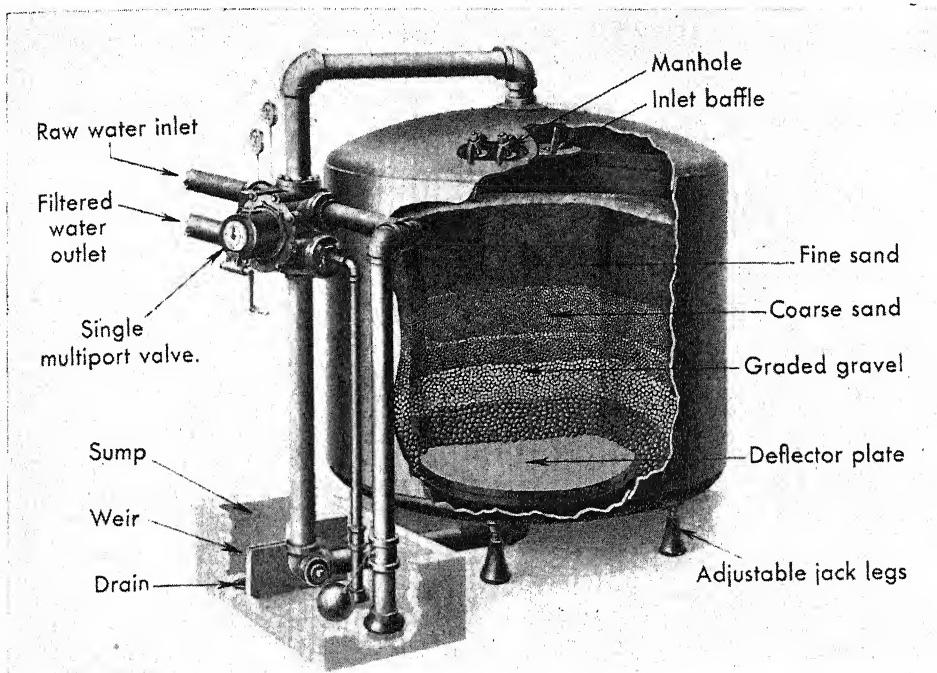


Fig. 160.—Pressure-type vertical sand filter.

Filters are usually supplied in batteries of two or more units so that, while one unit is out for backwashing and rewash, the other unit or units can carry the full load. Provision also must be made for supplying the backwash water at whatever rate is required. Turbid water is not suitable for backwashing because it fouls the filter bed; but settled water sometimes may be employed. Filtered water often is used for backwashing, and may be supplied by gravity from an elevated storage tank, or by a backwash pump from a clear well. Backwashing one filter unit with filtered water from the other units is also employed; but this plan means that the full filtering service of at least three units is required in order to backwash one unit.

Coagulation, settling, and filtration, when properly carried out, will remove turbidity, color, colloidal suspensions, organic iron, and/or manganese, and will effect

large reductions in microorganisms. Filtration cannot be depended on for complete removal of microorganisms and must be supplemented by other treatment, usually chlorination. Also, filtration, while it removes suspended matter, has no effect on the soluble mineral salts; these are therefore present in just as great an amount after as before filtration.

2. Sterilization

Chlorine is the most widely used sterilizing agent. It may be fed alone from cylinders of the liquid gas; it may be fed in conjunction with ammonia forming the

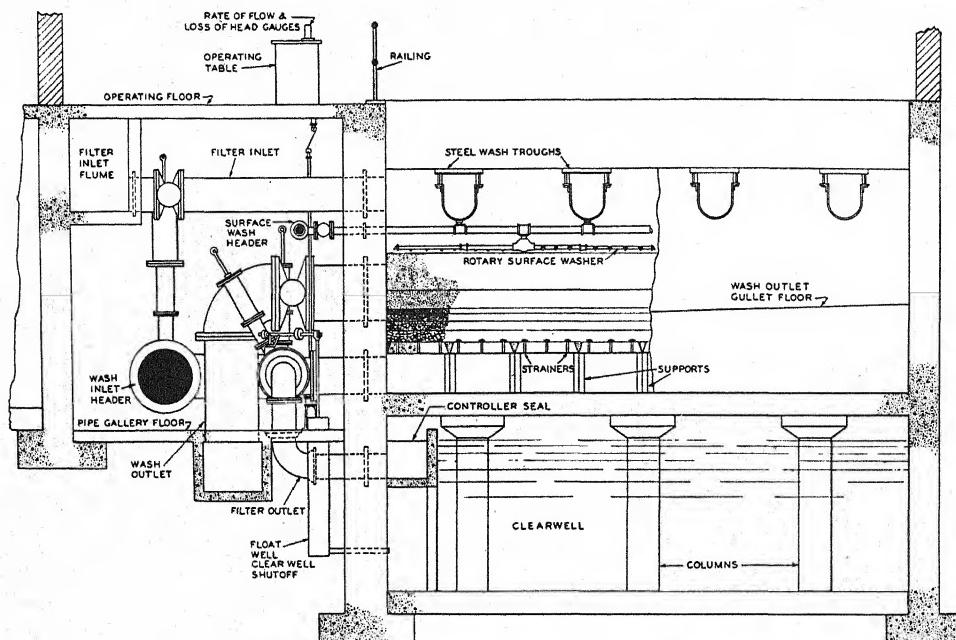


Fig. 161.—Gravity-type sand filter.

chloramines; or it may be fed in the form of a hypochlorite. As previously stated, it may be fed (1) before filtration (prechlorination), (2) after filtration (postchlorination), or (3) both before and after filtration. Chlorine is also employed to "burn out" color and other organic matter. When so used, the process is usually known as "superchlorination." It is also of value in oxidizing hydrogen sulfide and ferrous or manganous compounds. Heavy dosages of chlorine are frequently employed followed by dechlorination with a reducing agent or by treatment with an adsorbent usually activated carbon. Other sterilizing agents, used to a very limited extent with clear, filtered waters, are ozone and ultraviolet light.

3. Water Softening

Hardness in water is caused by soluble calcium and magnesium salts. It is the hardness in water which destroys soap, precipitates with alkalies, and forms scale or sludge in heaters, water lines, valves, fixtures, spray heads, sterilizers, water jackets, and steam boilers. The processes by which hardness is removed from water are called

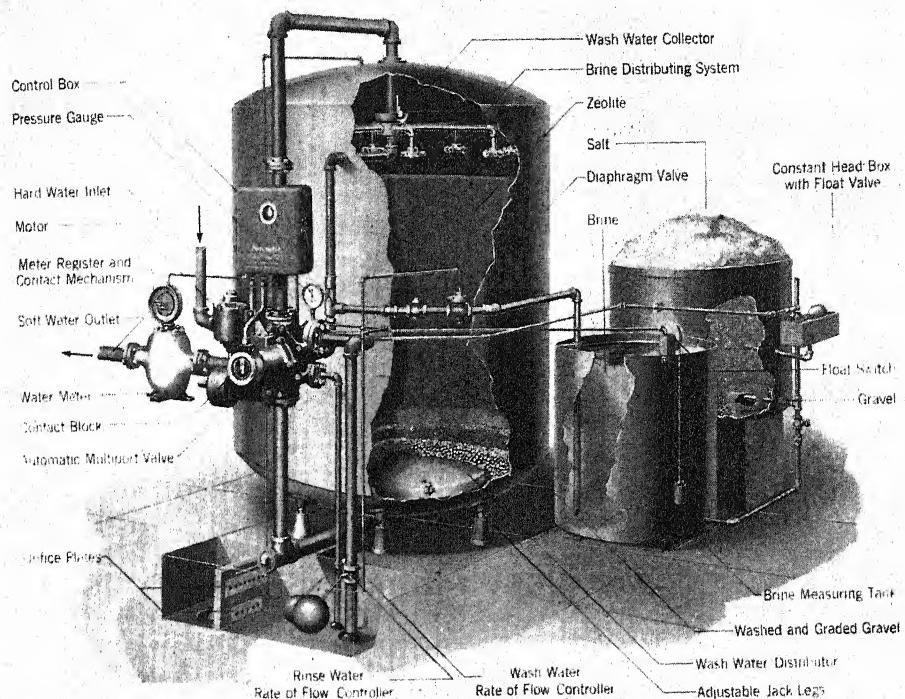


Fig. 162.—Automatic sodium zeolite water softener.

water softening. With the exception of distillation, which is too costly to be of any but limited applicability, there are three classifications for water-softening processes:

1. Cation exchange processes (usually known as base-exchange processes).
2. Cation plus anion exchange processes (demineralizing processes).
3. Precipitation processes (cold and hot lime or lime-soda processes).

In the first classification are the sodium and hydrogen cation exchange processes. The second classification embraces those processes in which the cations are first re-

moved by a hydrogen-ion exchanger; the mineral acids formed are next removed by an acid absorbent and then any carbon dioxide formed is removed by aeration. In the third classification are the cold lime (or lime-soda) processes used for process waters and preliminary treatment of boiler feedwater and the hot lime-soda process used almost exclusively for boiler feedwater.

(a) Sodium Zeolite Process

The sodium zeolite or sodium cation exchange process²⁻⁴ may be carried out in either gravity-type or pressure-type water softeners. As the latter is the kind almost universally used in industries, it is the one which will be described.

Figure 162 illustrates a zeolite water softener unit of the pressure type. It consists of a steel shell, designed to withstand whatever pressure will be encountered, holding a bed of granular zeolite, supported by several layers of graded gravel, lying over an underdrain or collector system. The water to be softened is admitted to the upper portion of the shell and uniformly distributed over the surface of the zeolite bed. It then passes evenly downward through the zeolite bed, during which passage the hardness-forming cations—calcium and magnesium—are removed by the ion-exchanging action of the zeolite and are replaced by sodium. This removal of hardness is so complete that the effluent from a zeolite water softener is known as “water of zero hardness” or, more commonly, as zero water. If soluble iron and/or manganese are present in the raw water, they will be removed simultaneously with the removal of the calcium and magnesium.

The softened water passes from the zeolite bed through the supporting layers of gravel and the collector system to the outlet of the softener, from which it passes through the meter to the service lines under whatever pressure is required. In manually operated zeolite water softeners, the hand on the meter is set for the predetermined amount of water which the unit will completely soften. At the end of the softening run, as indicated by the meter hand's returning to the zero point, the unit is taken out of service, regenerated, and restored to service. The softening runs with various zeolite water softeners, operating on various waters and under various conditions, range from slightly less than 4 hrs. to over 12 hrs. in length.

The regeneration period with various zeolite water softeners ranges from $\frac{1}{2}$ to 1 hr. There are three steps to this regeneration. The first step is backwashing, accomplished by passing a strong stream of water (6 g.p.m. per sq. ft. of bed area) upward through the softener. This loosens and regrades the zeolite bed, holds it in a suspended state, and removes, by washing up and out, any dirt which may have collected on top of the zeolite bed during the softening run. This backwashing takes from 7 to 10 min. The second step is the salting, effected by introducing into the softener a predetermined amount of a solution of common salt, by means of a

² E. Nordell, "Zeolites: Mining, Processing, Manufacture and Uses," *Michigan Eng. Bull.* **61**, Michigan State College, Jan., 1935.

³ H. L. Tiger, *J. Am. Water Works Assoc.*, **26**, 357 (1942).

⁴ H. F. Walton, *J. Franklin Inst.*, **232**, No. 4, 305 (1941).

hydraulic ejector which is an integral part of the softener. This salt solution is uniformly distributed over the surface of the zeolite bed and passes evenly down through it. As it does so, the salt reacts with the zeolite, removing the calcium and magnesium in the form of their very soluble chlorides and simultaneously restoring the zeolite to its original active or sodium condition. Salting takes from 5 to 10 min. The third and last step is the rinse, which consists of washing the calcium and magnesium chlorides, plus the excess salt, to the drain by means of a downward flow (2 to 3 g.p.m. per sq. ft. of bed area) of the rinsing water. After the rinse, which ranges from 18 to 40 min., the softener unit is returned to service, ready to soften a further equal quantity of hard water.

In order to insure an uninterrupted soft-water service, zeolite water softeners are often supplied in batteries of two or more units, so designed and operated that the other unit or units of the battery will handle the full softening load while one unit is regenerated. In other cases, soft-water storage tanks may be employed to tide over the regeneration periods.

Completely automatic⁵ zeolite water softeners are available in which a motor-driven multiport valve, coupled with electrical controls, serves to perform all of the operations formerly performed by hand. In these, the length of the softening run is governed by a water meter equipped with an electric contact head; the length of the backwash period is controlled by an electric time switch; the volume of salt brine ejected into the softener is governed by an electric float switch in a brine measuring tank; and the rinsing period is controlled by an electric time switch.

(b) Hydrogen Cation Exchange Process

In the past few years, new types of zeolite—organic or carbonaceous, *i. e.*, organic cation exchangers have come into use. In the sodium cycle, these behave much the same as the siliceous zeolites; that is, they exchange sodium ions for calcium or magnesium ions on the softening run and at the end of the softening run are regenerated with salt. It is in the hydrogen cycle,⁶⁻¹⁸ however, that their behavior is different. Here, bicarbonates are removed from water completely, leaving practically nothing in the water but carbon dioxide, which is then easily removed by aeration. In ad-

⁵ S. B. Applebaum, *J. Am. Water Works Assoc.*, **26**, 607 (1934).

⁶ B. A. Adams and E. L. Holmes, *J. Soc. Chem. Ind.*, **54**, 1-6T (1935).

⁷ H. L. Tiger, *Trans. Am. Soc. Mech. Eng.*, **60**, 315 (1938); **64**, 49 (1942).

⁸ S. B. Applebaum and R. Riley, *Ind. Eng. Chem.*, **30**, 80 (1938).

⁹ S. B. Applebaum, *J. Am. Water Works Assoc.*, **30**, 947 (1938).

¹⁰ S. B. Applebaum, *J. Am. Water Works Assoc.*, **32**, 583 (1940).

¹¹ S. B. Applebaum, *Power Plant Eng.*, **45**, 69 (1941).

¹² S. B. Applebaum, *Mech. Eng.*, **56**, 341 (1934).

¹³ S. J. Broderick and D. Bogard, *Ind. Eng. Chem.*, **33**, 1291 (1941).

¹⁴ R. Griessbach, *Beih. Z. Ver. Deut. Chem.*, **31**, 1-16 (1939); *Angew. Chem.*, **52**, 215 (1939).

¹⁵ R. J. Myers, J. W. Eastes, and S. F. Myers, *Ind. Eng. Chem.*, **33**, 697 (1941).

¹⁶ R. J. Myers, J. W. Eastes and D. Urquhart, *Ind. Eng. Chem.*, **33**, 1270 (1941).

¹⁷ R. J. Myers and J. W. Eastes, *Ind. Eng. Chem.*, **33**, 1203 (1941).

¹⁸ R. Riley, *Paper Mill and Wood Pulp News*, **61**, 20 (Sept., 1938).

dition, they remove, not only calcium and magnesium ions, but also sodium ions. It is thus now possible to eliminate sodium bicarbonate from water without having to resort to distillation. Iron and/or manganese, if present in soluble form, may be removed by carbonaceous zeolites in the hydrogen cycle, in the same manner as, and simultaneously with, the removal of calcium, magnesium, and sodium.

When the capacity of an organic cation exchange unit for producing a completely softened water is exhausted, the unit is cut out of service and backwashed. It is then *regenerated* with dilute acid, usually sulfuric acid, which converts the calcium, magnesium, sodium, iron, etc., to their soluble sulfates and restores hydrogen to the exchanger. The sulfates and excess acid are then completely rinsed out of the unit, after which it is returned to service, ready to soften a further equal quantity of the hard raw water.

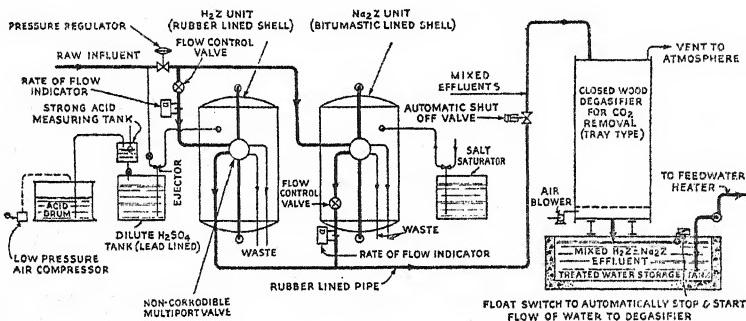


Fig. 163.—Flow diagram of a hydrogen cation exchange unit and a sodium cation exchange unit operating in parallel.

When waters which contain sulfates or chlorides in addition to the bicarbonates, are softened through the hydrogen-cation exchange process, the corresponding mineral acids are formed. Therefore, in handling such waters, it is necessary to neutralize this acid. If the chloride and sulfate content is low, it is often feasible to neutralize the aerated effluent with small dosages of alkali. In other cases, it may be more economical to run one or more of the organic cation exchange units on the sodium cycle and mix this effluent with the hydrogen-ion exchanger effluent in such proportions as to yield whatever alkalinity is desired in the mixed effluent (see Fig. 163). As the effluent from the hydrogen-ion exchange process usually contains a considerable amount of free carbon dioxide, the effluent is usually passed through an aerator or degasifier to effect its removal.

(c) Demineralization

While the bicarbonates of calcium, magnesium, and sodium may be practically eliminated from water by the hydrogen-ion exchanger, the chlorides and sulfates are not. Instead, they appear in the effluent as hydrochloric and sulfuric acids. These

mineral acids may be eliminated¹⁹ by passing the effluent from the hydrogen-ion exchanger through an acid absorbent or anion exchanger. The reaction that takes place is either an anion exchange, with the hydrogen ion uniting with an hydroxyl ion to form water while the anions of the acids are taken up by the organic radical

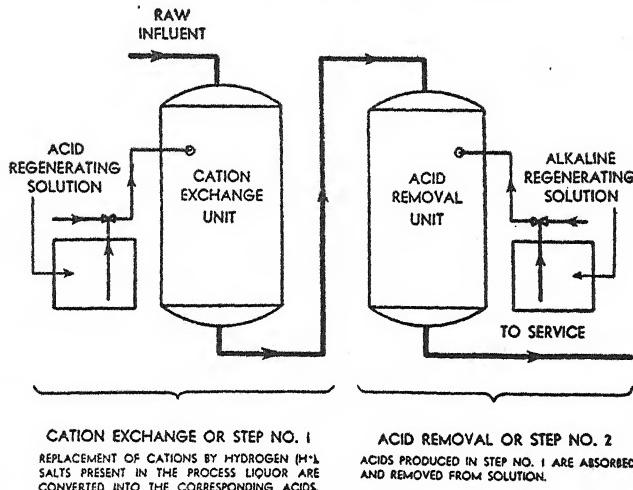


Fig. 164.—Demineralizing process.

of the exchanger, or an absorption of entire acid molecules with the formation of the hydrochloride and sulfate of the organic radical. In either case, the practical results are the same—that is, almost complete removal of the mineral acids is effected. The equipment used in this process consists of a hydrogen-ion exchange unit (cation exchanger) followed by an acid absorbent unit (anion exchanger) as shown in Fig. 164. The effluent is then freed from carbon dioxide by aeration, usually effected in a degasifier or decarbonation tank.

TABLE 83
MINERAL MATTER IN DISTILLED WATER
(All results expressed in p. p. m.)

Sample	A	B	C	D	E	F	G	H	I
Total hardness as CaCO_3	0	6	10	10	0	0	0	15	1
Total alkalinity as CaCO_3	13	9	18	15	5	5	4	12	2
Chlorides as Cl	4	0	0	0	2	2	1	2	0
Sulfates as SO_4	0	0	0	0	2	3	3	5	1

Tables 83 and 84^{19a} show the analyses of nine commercially distilled waters compared with analyses of effluents from seven demineralizing plants. Analyses of the raw waters employed and cost data are included.

¹⁹ H. L. Tiger and S. Sussman, *Ind. Eng. Chem.*, 35, 196 (1943).

^{19a} E. Nordell, *Chem. & Met. Eng.*, 50, No. 10, 112 (1944).

TABLE 84

ANALYSES AND COST DATA FOR INDUSTRIALLY DEMINERALIZED WATER

Plant	Hardness, p. p. m. as CaCO_3		Alkalinity, p. p. m. as CaCO_3		Chlorides, p. p. m. as Cl		Sulfates, p. p. m. as SO_4		Cost of treatment, cents per 1000 gal.
	Raw	Demin.	Raw	Demin.	Raw	Demin.	Raw	Demin.	
J	43	0 ^a	34	3	4	0	19	0	3.0
K	61	0	24	2	8	0	26	0	4.9
L	116	0	58	3	2	0	70	0	8.2
M	120	0	93	4	33	0	38	0	9.5
N	212	0	140	6	24	2	80	1	15.3
O	261	0	188	2	10	0	60	0	11.5
P	302	1	227	4	25	0	60	1	16.0

^a Zero, as used, means less than 1 p. p. m.

(d) Cold Lime (or Lime-Soda) Process

With the ion exchange processes, the effluent produced is usually so extremely low in hardness that it is commonly known as water of "zero hardness." For many purposes such a complete removal of hardness is both unnecessary and uneconomical. This is the case with many brew waters, carbonated beverage waters (see page 827), cooling waters, etc. In such cases, the cold lime process²⁰⁻²² of water softening is often employed. This is a precipitation process in which the precipitants—lime (or lime and soda ash) plus, usually, a small amount of a coagulant—are added to the cold water. They react with the hardness components to form precipitates which are removed by settling or by settling and filtration.

The dosages of chemicals employed depend upon the results desired. For instance, if it is desired to reduce only the calcium bicarbonate content, then just sufficient lime is added to accomplish this purpose. If it is desired to reduce the magnesium content also, then more lime is added; and if noncarbonate hardness is to be reduced, then soda ash also is added. The function of the lime is to remove carbon dioxide, to change the bicarbonates to the carbonates, and, if necessary, to change magnesium compounds to the hydroxide. The function of the soda ash is to change the noncarbonate hardness to the carbonates. In addition, a coagulant, usually aluminum sulfate, is frequently employed to aid in settling the precipitates. In the cold lime process, calcium is precipitated as the carbonate, while magnesium is precipitated as the hydroxide. The lime which is added is precipitated as calcium carbonate. If calcium hardness alone is removed, the sludge consists principally of calcium carbonate; if both calcium hardness and magnesium hardness are removed, the sludge contains both calcium carbonate and magnesium hydroxide.

The latest type of cold lime-soda water softener is the *precipitator* (Fig. 165), which is designed so that the raw water is thoroughly mixed with, and then filtered through,

²⁰ E. Nordell, *Paper Trade J.*, 112, No. 18, 37 (1941).

^{20a} C. H. Spaulding, *Water Works & Sewerage*, 85, No. 3, 153 (1938).

²¹ C. H. Spaulding, *J. Am. Water Works Assoc.*, 29, No. 11, 1697 (1937).

²² S. B. Applebaum, *Ind. Eng. Chem.*, 32, 678 (1940).

a previously formed sludge. This intimate contact with the solid phase inhibits supersaturation and, therefore, produces a stable effluent. The detention period in the precipitator need therefore be only 1 hr. instead of the 4 hrs. required in the older types. The flow of the water in the precipitator is downward through the centrally disposed mixing chamber, where it is mixed with the required dosages of chemicals and thoroughly agitated with previously formed sludge. Emerging from ports at the bottom of this chamber, it then filters upward through a suspended blanket

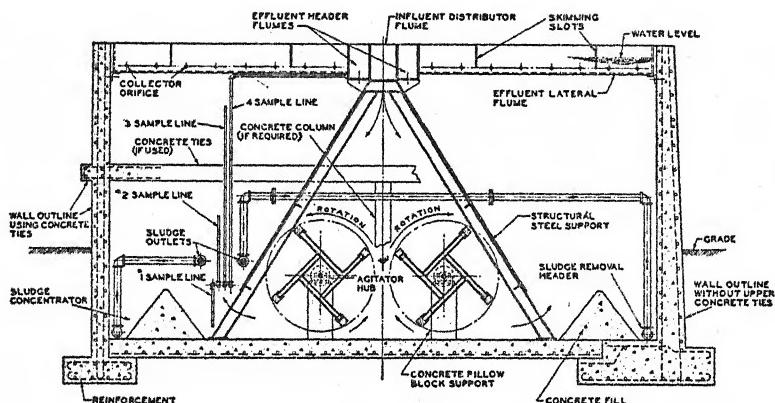


Fig. 165.—Rectangular precipitator for cold lime or lime-soda process.

of sludge, the height of which is kept at a constant level by bleeding off (through a concentrator) the excess sludge as fast as formed. As the water rises through this outer compartment, a very thorough settling is effected because, due to its constantly increasing cross-sectional area, the upward velocity of the treated water constantly decreases. And because of this decreasing upward rise, a plane is reached at which the upward flow is too slow to lift the precipitates any further; the precipitates are consequently left behind. In practice, this plane of demarcation between suspended precipitates and settled water is clearly defined. The settled water then flows from a collecting trough at the top of the precipitator, either directly to service or through filters to service.

(e) Hot Lime-Soda Process

In the hot lime-soda process²³⁻²⁵ of water softening, the water is first heated to temperatures at or near the boiling point; it is next treated with the required dosages of hydrated lime and soda ash, then settled, and finally filtered. The lime and soda ash react with the hardness to precipitate the calcium and magnesium in the raw

²³ S. T. Powell, I. G. McChesny, and F. Henry, *Ind. Eng. Chem.*, 30, 400 (1938).

²⁴ J. D. Yoder and H. Moshammer, *Power*, 82 (Sept., 1938).

²⁵ J. D. Yoder, *Power Plant Eng.*, 42, 134, 143 (1938).

water, plus the added lime, as a sludge consisting of calcium carbonate and magnesium hydroxide.

The equipment used in this process (Fig. 166) when treating water for high-pressure steam boilers usually consists of the following five elements: primary heater, chemical feeds, settling tank, deaerating heater, and filters. In softening boiler feedwaters for low-pressure boilers, the fourth element—the deaerating heater—is often omitted.

Exhaust steam is employed to heat the raw water; and, where a deaerating heater is employed, all the steam used is first passed through the hot, treated water in the deaerating heater, thus effecting a complete scrubbing and deaeration before it passes to the primary heater. In the primary heater, the water is sprayed down through

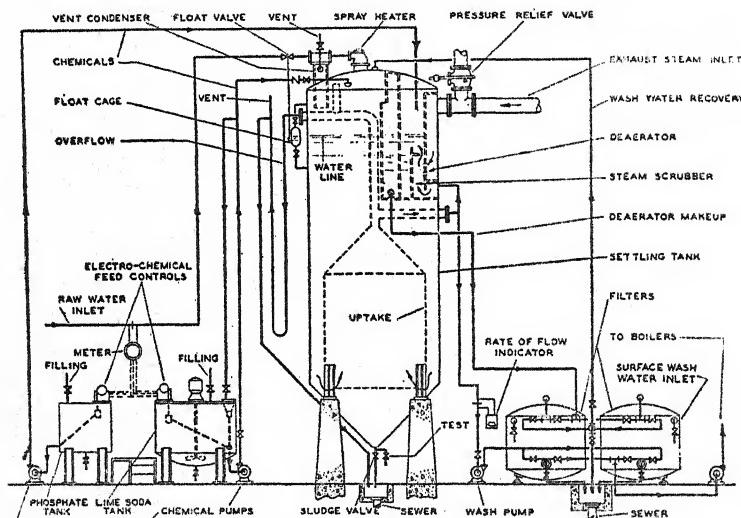


Fig. 166.—Hot lime-soda water softener.

the steam in the head of the settling tank. This heating liberates the free carbon dioxide and the dissolved oxygen and nitrogen from the water and discharges them, either through a vent or a vent condenser, to the atmosphere. The deaeration taking place in this primary heater is sufficient to lower the dissolved oxygen from saturation limits to less than 0.3 ml. per liter.

The chemicals, hydrated lime and soda ash, are charged, in weighed dosages in known volumes of water, into the chemical feeding tank, where a mechanically driven agitator serves to keep the lime in an even suspension. As for the soda ash, of course, both it and any caustic soda formed from it are wholly soluble and therefore evenly distributed. The feeding device draws off dosages of the chemicals proportionate to the volumes of water passing through the raw water meter. A chemical pump then lifts these chemical dosages and discharges them into the heated water in the upper portion of the settling tank.

As the chemicals come in contact with the hot water, they react with it to precipitate both the lime in the water and the added lime as calcium carbonate, and the magnesium as magnesium hydroxide. These precipitates grow larger and heavier as the water passes slowly downward in the settling tank. When the water reaches the lower edge of the drawoff chamber and rises slowly through it, the precipitates continue to fall to the conical bottom of the settling tank, where they collect as a sludge. This sludge is drawn off periodically to waste by means of a manually operated or automatically operated sludge valve.

From the drawoff chamber, the water then passes to the deaerating heater, which may be an integral part of the settling tank, as shown, or a separate piece of equipment. In this, the water is thoroughly scrubbed with all of the steam required for the primary heater. As the temperature of the water entering the deaerator is within a couple of degrees of the temperature of the steam, a very complete deaeration is effected, furnishing an effluent with less than 0.01 ml. of dissolved oxygen per liter. The settled water from the deaerator, containing but a relatively small amount of flocculent matter, is then passed through filters from which it is delivered to service. These filters are of the closed, pressure type and are filled with a nonsiliceous filter medium which is usually carefully graded Anthrafilt. The reason for using non-siliceous material in place of the customary sand and gravel is to eliminate all danger of silica pickup by the hot alkaline effluent of the settling tank.

Since backwashing of the filters with cold raw water would not only result in the wastage of softened water, chemicals, and heat units, but would also cause clogging deposits to form in the filter medium, backwashing is performed with hot, settled water. This is drawn off by means of a backwash pump, forced upward through the filter unit and back to the top of the settling tank being thereby recovered. The filters are usually supplied in batteries of two or more filter units so designed that, when one unit is out for backwashing, the other unit or units of the battery can carry the full softening load. In this way, the soft-water service is made continuous. Following the softening plant, various corrective chemicals, such as phosphate, may be employed; these are often introduced directly into the boilers to avoid the formation of deposits in the boiler feed lines.

4. Removal of Other Impurities

(a) Iron

In deep well waters, iron is almost invariably present as ferrous bicarbonate. Such waters are clean and colorless when first drawn but, on exposure to the air, cloud up and slowly deposit yellowish to reddish-brown ferric hydroxide. The iron may be removed²⁶⁻²⁸ from such waters by the following three methods: Aeration, settling, and filtration; base exchange; and manganese zeolite.

²⁶ S. B. Applebaum and M. E. Bretschger, *Ind. Eng. Chem.*, **26**, 925 (1934).

²⁷ E. Nordell, *J. Am. Water Works Assoc.*, **28**, No. 10, 1480 (1936).

²⁸ D. J. Saunders, *Water Works Eng.*, **92**, 310 (1939).

Aeration may be effected by various types of aerators, of which the coke tray aerator is the most widely used type for iron removal. Aeration removes from the water free carbon dioxide and introduces nitrogen and oxygen. The nitrogen is inert, but the dissolved oxygen reacts with the ferrous bicarbonate to precipitate ferric hydroxide and liberate carbon dioxide. In waters of low total solids content and rather low ρH values, oxidation of the iron is slow; in such cases, building up the ρH value with soda or lime is of value in speeding up the oxidation. If the water is also being treated by the cold lime or lime-soda process, then the aerator may be placed over the settling tank or precipitator. In other cases, a catch basin is placed under the aerator and the water from the catch basin is passed to the filters. The sizes of catch basins employed vary considerably, but basins having $\frac{1}{4}$ - to $\frac{1}{2}$ -hr. detention periods are rather widely employed. From the catch basin, the water is passed through the filters by gravity or by pumping. When properly carried out, the content of iron in the effluent will be less than 0.1 p. p. m.

Iron in the form of ferrous bicarbonate also may be removed by cation exchange in the zeolite softener. This may be carried out simultaneously with the removal of hardness; and many zeolite plants are used for the double purpose of water softening and iron removal. On the softening run, the iron goes into the zeolite and is replaced by sodium; on regenerating with salt, the sodium goes into the zeolite and the iron comes out in the form of ferrous chloride, which is washed to the drain with the other waste products and excess of salt. In this process, only pressure zeolite water softeners of either the greensand zeolite or organic cation exchanger type should be used, and contact of the water with air ahead of the softeners should be avoided.

The removal of iron by manganese zeolite is applicable where the iron content of the water does not greatly exceed 1 p. p. m. and where simultaneous softening of the water is not desired. Manganese zeolite is made by treating a sodium green-sand type of zeolite first with manganous chloride and then with potassium permanganate. The permanganate precipitates the higher oxides of manganese in the zeolite. When water containing ferrous bicarbonate is filtered through manganese zeolite, the iron is oxidized to ferric hydroxide, and is removed from the water by the filtering action of the manganese zeolite bed. As this iron accumulates, it is removed at intervals by backwashing. When the oxidizing action of the bed is nearly exhausted, the unit is cut out of service, backwashed, regenerated with a solution of a predetermined amount of potassium permanganate, rinsed, and returned to service ready to deferrize another equal amount of iron-bearing water.

In surface waters, iron, if present in amounts of above 0.1 p. p. m., is usually present either in colloidal or organic form. Iron in this form may be removed along with the turbidity and color by coagulation, settling and filtration, as has been previously described on pages 806-808.

Iron in the form of ferrous sulfate may be found in acid mine waters or acid river waters contaminated either with industrial acid wastes or seepage of mine waters. In this form it is removed by neutralization with soda or lime, aeration, settling and filtration.

(b) *Manganese*

Manganese,^{26, 27} which occurs less often in troublesome amounts than iron, is found in much the same forms—that is, in clear, deep well waters it may occur as manganous bicarbonate, in surface waters as colloidal or organic manganese and in acid waters as the sulfate.

Manganese present as manganous bicarbonate may be removed by the same processes as those described for the removal of iron. However, when removing manganese by aeration, settling, and filtration, it is usually necessary to carry a high *pH* value in order to oxidize the manganese. It is also necessary to run new equipment for a while until the coke trays and sand grains in the filters "ripen" a bit, that is, until some deposits of manganese oxides collect to assist the oxidation by catalysis.

Manganese present as manganous bicarbonate also may be removed by the ion-exchanging action of the zeolite softener or by the oxidizing action of the permanganate regenerated manganese zeolite. Manganese in acid waters, or organic or colloidal manganese in surface waters may be eliminated by the same methods employed for iron removal—with acid waters, by neutralization, aeration, settling, and filtration, and with surface waters, by coagulation, settling, and filtration.

(c) *Hydrogen Sulfide*

Methods of hydrogen sulfide removal are: (A) simple aeration; (B) chlorination; and (C) degasification with flue gas followed by aeration to remove the carbon dioxide introduced by the flue gas.^{29, 30}

Method A (simple aeration) usually will remove only a portion of the hydrogen sulfide and, therefore, is unsatisfactory except with waters of initially low hydrogen sulfide content. Method B (chlorination) is likewise of limited applicability but for another reason—the high cost of treatment, 8 p. p. m. of chlorine being required to oxidize completely each p. p. m. of hydrogen sulfide present. Chlorination is of value where the hydrogen sulfide content is low, as is the case with some raw waters, or for removing the last trace of hydrogen sulfide from an aerated water. Method C (degasification with flue gas followed by aeration) is widely applicable and in practice has been found to be an efficient and economical method of removing hydrogen sulfide.

Method C is carried out in a two-chambered degasifier, the upper chamber of which is enclosed and the lower chamber of which is open to the atmosphere. As the water rains down over a series of superimposed slat trays in the upper chamber, it is met by a countercurrent stream of scrubbed flue gas, drawn from the stack, which is admitted through ports in the lower portion of this chamber and discharged from vents in the top of the chamber. The carbon dioxide of the flue gas dissolves in the water, lowers its *pH* value, and liberates the hydrogen sulfide which, with the spent flue gas, is then discharged through the vents. In the lower, open chamber of the degasifier, the hy-

²⁹ E. Nordell and C. E. Richheimer, *Paper Trade J.*, 110, No. 12, 47 (1940).

³⁰ E. Nordell, *Paper Ind. Paper Works*, 23, No. 6, 562; No. 7, 666; No. 8, 787 (1941).

drogen sulfide-free water rains down over a series of superimposed slat trays through the atmosphere. The aeration effected in this lower chamber removes the carbon dioxide introduced into the water by the flue gas. Activated carbon is occasionally employed for the removal of small amounts of hydrogen sulfide. Since its capacity for absorbing hydrogen sulfide is rather small, its application for this purpose is limited.

(d) *Taste and Odor*

Objectionable tastes and odors may be removed from water by the use of the adsorptive powers of activated carbon.³¹⁻³³ For these purposes two forms of activated carbon are employed—powdered and granular.

Powdered activated carbon is widely employed in conjunction with coagulation and settling processes or with the cold lime or lime-soda process of water softening. In these cases, it is added directly to the water in the tanks, basins, or precipitators and the bulk of it settles out in the sludge. Because of the intimate contact afforded, the sludge blanket type of equipment, such as the precipitator, is especially efficient and effects savings of as much as 40% in the dosages of activated carbon required.

Granular activated carbon is employed in activated carbon purifiers or filters. In these, the water is filtered through a bed of the granular material. As the capacity of the activated carbon for the removal of most tastes and odors is high, renewal of the bed of granular material is usually required only after it has been in use for about a year. Reactivation of the used granular material may be effected but, in actual practice, is seldom carried out. Instead, it is usually discarded and the filter is re-filled with new material.

(e) *Silica*

Silica forms three types of boiler scale. If soluble aluminum compounds are present, it may form an aluminosilicate scale such as analcite. If calcium is present, it may form a calcium silicate scale. In other cases, the scale may consist almost entirely of silica.

These scales are usually most troublesome in high-pressure boilers. In low-pressure boilers, silica scales may usually be avoided by having a soluble phosphate present and twice as much methyl orange alkalinity as silica present in the boiler salines. In this way, as much as 350 p. p. m. of silica may be kept in solution in the boiler salines. In high-pressure boilers, low alkalinites are preferred in the boiler salines in order to keep the carbon dioxide content of the steam as low as possible. Under such conditions, the silica content in the boiler salines must be low, usually under 60 p. p. m. and, in some cases, as low as 15 p. p. m. Reduction of the silica content of the raw water is therefore frequently required.

Silica removal is effected by the adsorptive action of certain metallic oxides or

³¹ G. A. Burn, *Eng. Contract Record*, 55, No. 15, 42 (1942).

³² J. W. Hassler, *West Va. Pulp and Paper Co.* (1941).

³³ E. A. Sigworth, *J. Am. Water Works Assoc.*, 29, 688 (1937).

its hydroxides, notably those of magnesium.^{34, 35} Ferric hydroxide is also employed but adsorptive powers for silica are much lower than those of magnesia. In addition, the ferric hydroxide process, since it employs ferric sulfate and soda, increases the total dissolved solids, which is not the case with the magnesia process. The forms in which magnesia is employed are: as the hydroxide, precipitated *in situ*; as dolomitic lime; as the carbonate; and as the oxide. When the cold lime-soda or hot lime-soda process of softening is employed, the magnesium hardness which is precipitated from the water adsorbs some of the silica. If not enough magnesium hardness is present to effect the desired reduction, then the required amount of one of these magnesium compounds is added. As ionic magnesium, precipitated as the hydroxide *in situ*, is most effective, dissolvers are often employed. In these, magnesium oxide or hydroxide is brought in contact with the cold, raw water. The free carbon dioxide and bicarbonates in the water react to form magnesium carbonate which is soluble to the extent of somewhat over 100 p. p. m. In the softener, this reacts with lime to precipitate magnesium hydroxide.

Intimate contact with an excess of the magnesia sludge is necessary for efficient silica removal. These conditions exist in the sludge-blanket type of cold lime-soda water softener. In other types of equipment, recirculation by means of a pump may be employed.

Complete removal of silica is not required and is not attempted because it is uneconomical. Instead, a reduction to a content below that at which scale forms is sufficient. This tolerance varies with the total solids content of the boiler feedwater, the extent to which these solids are concentrated in the boiler, the pressure employed, and other operating conditions. In general, reductions of silica to some 3 to 6 p. p. m. are effected, the exact amount varying, as stated, according to the requirements of each case.

(f) Oil

While the condensates from steam turbines are usually free from oil, those from reciprocating engines are generally badly contaminated. Oil may be removed from such condensates by coagulation with aluminum sulfate and an alkali, followed by filtration through a nonsiliceous filter medium such as Anthrafilt. The oil is caught in the floc formed, and the floc with the entrained oil is then strained out of the condensate by the filter. The filter is operated in much the same manner as the usual sand filter but, in addition to periodical backwashings, occasional washes with a hot caustic soda solution are required.

II. THE TREATMENT OF COOLING WATER

The processes used for the treatment of cooling water³⁶ are the cold lime process, the sulfuric acid process, and the sodium zeolite process. The *sulfuric acid process*

³⁴ H. L. Tiger, *Trans. Am. Soc. Mech. Eng.*, **64**, 49 (1942).

³⁵ J. D. Yoder, *Southern Power and Industry*, **59**, No. 2, 103 (1941).

³⁶ S. B. Applebaum and T. P. Browne, *Steam Plant Eng.*, **1**, No. 12, 22 (1932).

consists of adding enough sulfuric acid to the water to stop scale formation in the cooling system. This converts bicarbonates to the more soluble sulfates. As to the amounts of sulfuric acid to be used, this depends on the composition of the water, the temperatures reached in the cooling system, and whether the water is to be used once or recovered through cooling towers and re-used.

The process most applicable to a particular cooling water depends upon several factors. In some cases, the water is used as boiler feedwater after being used for cooling purposes. In such a case, the sodium zeolite process is often employed. If the water is high in bicarbonate hardness, a combination process consisting of cold lime treatment, followed by complete softening with zeolite, may be employed.

If the cooling water is used only for cooling purposes but is recovered through cooling towers and re-used, the sodium zeolite process, the combination lime process followed by the zeolite process, or the sulfuric acid process may be used.

If the cooling water is used only once and then run to waste, either the cold lime process or the sulfuric acid process may be used. For the cold lime process, as used for the treatment of cooling water, it is usually necessary only to add enough lime to reduce the calcium alkalinity to about 35 p. p. m. Precipitation of magnesium is rarely required as the solubility of magnesium carbonate is about 100 p. p. m. and amounts of magnesium alkalinity under this will not form scale in the once-through cooling system. For the noncarbonate hardness, no reduction is necessary because it will not form scale in a once-through system.

If the water is not to be re-used, the acid is added to the water under pressure and the carbon dioxide, formed by reaction with the bicarbonates, is retained in the water. In this way, since the solvent effects of the liberated carbon dioxide are used, less acid is necessary than if the carbon dioxide were allowed to escape.

If the acid water is recovered over cooling towers and re-used, then practically all of the carbon dioxide formed is eliminated in the first pass. Therefore, in such cases, a much greater amount of sulfuric acid is required than in the once-through system.

In passing through the cooling towers, some of the water is evaporated and the salines are therefore concentrated. In order to prevent the formation of calcium sulfate scale in the cooling system, the cooling pond or basin should be blown down enough to keep the concentration of calcium sulfate below 1700 p. p. m.

III. GENERAL WATER REQUIREMENTS FOR ALL FOOD INDUSTRIES

The water used in all food industries should be: clear, colorless, odorless, tasteless, iron free, manganese free, and bacteriologically acceptable.

1. *Clarity:* The U. S. Public Health Service *Drinking Water Standards* state that turbidity shall not exceed 10 p. p. m. (Silica Scale).
2. *Color:* The U. S. Public Health Service *Drinking Water Standards* state that color shall not exceed 20 p. p. m. (Standard Cobalt Scale).
3. *Odor:* The water should be free from odors.
4. *Taste:* The water should be free from objectionable tastes.

5. *Iron:* The iron content should not exceed 0.1 p. p. m.
6. *Manganese:* The manganese content should not exceed 0.1 p. p. m.
7. *Bacteria:* Even for products sterilized in sealed containers, the bacteriological quality of all water used throughout the plant should, at all times, at least meet the standards required for drinking water.

For safe and economical operation of all steam boilers, the *boiler feedwater* should be treated. With waters low in hardness to be used in low-pressure boilers, internal treatment may be practical. External treatment is preferable with all other waters. The boiler feedwater may be softened by the sodium zeolite process, the hydrogen-ion exchange process or the hot lime-soda process. Where the sodium zeolite process is used for process water, the boiler feedwater is usually, but not necessarily, softened by the same method. Where open steam is employed, the steam should be free from oil and mechanical carry-over of mineral solids. The exhaust steam from reciprocating engines will contain oil, while exhaust steam from turbines will be free from oil. Mechanical carry-over of mineral matter from the boiler may be prevented by proper treatment of the water and by blowing off sufficiently, preferably continuously, to keep the concentration of the boiler salines below the danger point.

In *cooling water* systems, calcium bicarbonate is the principal source of scale as it decomposes to form calcium carbonate. Whether the cooling water requires treatment and, if so, the kind of treatment depends on a number of factors such as the bicarbonate content of the water, whether or not it is to be re-used either for cooling or some other purpose, the seriousness of scale formation, and the economics involved. Cooling waters are treated by the zeolite process, the cold lime alum plus acid treatment, or the sulfuric acid treatment.

IV. SPECIAL WATER REQUIREMENTS FOR VARIOUS INDUSTRIES

In addition to the general water requirements, special requirements for the water used in various food industries are sometimes necessary.

1. Baking

In the manufacture of bread, an appreciable amount of calcium salts is necessary for proper fermentation. With waters deficient in calcium salts, calcium sulfate or prepared mixtures of salts may be employed. While calcium salts are beneficial for yeast growth, large amounts of magnesium salts are claimed to be detrimental. Control of the *pH* value is also exceedingly important.

A water supply subject to appreciable changes in composition may affect the formulas employed. Removal of the hardness, usually by the sodium zeolite process plus rebuilding of the hardness to a set figure plus proper control of the *pH* value, have been advocated for such waters. This also applies to chains having a number of bakeries operating on various waters in various locations. Water of zero hardness is often employed for cracker and cake making, because it is claimed that it yields a better and more uniform product.

Water used for cleansing purposes throughout the bakery should be soft. Zeolite water softeners are commonly employed for this purpose; and, where made available, zeolite-softened water is almost invariably used for the boilers also. In other cases, the hot lime-soda process or the hydrogen zeolite process may be employed for softening the boiler feedwater. Special care should be taken to keep the concentration of the salines in the boiler low enough so that carry-over is eliminated.

2. Bottling

In addition to meeting the general requirements, the water used³⁷ for making carbonated beverages (see page 721) should be low in alkalinity. Low alkalinity is required because high alkalinities neutralize some of the acidity of the sirup and thereby kill much of the zest or tang of the beverage. The limits of alkalinity vary somewhat with different sirup or extract manufacturers. Some require that the alkalinity should not exceed 100 p. p. m., expressed as CaCO_3 ; others set a limit of not over 80 to 85 p. p. m.; and some require not over 50 p. p. m. Where the alkalinity exceeds the recommended limit, the water should be treated to reduce it below or at least to this point. Reduction of alkalinity is usually accomplished by treatment with lime and alum in the cold lime water softener. Soda ash is not used, as reduction of the noncarbonate hardness is not required. Chlorination, usually with a hypochlorite, is almost invariably applied in the cold lime-alum water softener, and the excess chlorine is later taken out by an activated carbon filter. The usual hookup consists of:

1. Chemical feeds for lime, alum, and hypochlorite.
2. Cold process lime water softener.
3. Sand filters.
4. Activated carbon filters.

Most sirup manufacturers recommend that at least a sand filter with coagulant feed and activated carbon filter be used on every municipal water supply no matter how satisfactory it may ordinarily be. They consider this a necessary form of insurance against the chance of turbidity or corrosion deposits from pipe lines or temporary off-tastes or odors occasionally getting into the beverage.

Organic cation exchangers operating on the hydrogen cycle are also employed for alkalinity reduction. If the water being handled contains sulfates and chlorides, the requisite portion of untreated water is by-passed around the softener and mixed with the hydrogen-ion exchanger effluent to neutralize the acid and furnish a slight alkalinity.

Sterilization of the water alone will not prevent growths in the beverages. The most scrupulous care must be used in handling the sirups and in bottling operations to avoid the introduction of microorganisms from sirup, bottles, caps, or the atmosphere.

³⁷ D. J. Saunders, *The Natl. Carbonator and Bottler* (1939).

If iron or manganese is present, it may be removed in the cold lime process water softener by aeration of the water as it enters the softener. Hydrogen sulfide may be removed by chlorination alone or by aeration followed by chlorination.

The preceding discussion refers to water used for making the beverage. For soaking, bottle washing, general cleansing purposes, and boiler use, completely softened water is best and may be obtained by the use of a separate zeolite water softener plant.

3. Brewing

The water used in a brewery³³⁻⁴¹ may be divided into four classifications as follows: brew water; boiler feedwater; water for bottle washing, keg washing, and pasteurizing; and cooling water.

Brew Water.—In addition to meeting the general requirements, the brew water used for making light-colored beers or ales should be low in alkalinity and high in calcium sulfate hardness. If the water supply is low in alkalinity and high in sulfate hardness, it may require no treatment. If it is low in alkalinity and low in sulfate hardness, the addition of calcium sulfate plus, if desired, some sodium chloride may be all that is required.

With brew waters high in bicarbonate hardness, the cold lime-alum process water softener is usually used. If the water is deficient in sulfate hardness, calcium sulfate and sodium chloride, if desired, are added. The usual equipment would consist of: chemical feeds (lime, alum, calcium sulfate, salt); cold process lime water softener; and filters. Some breweries use powdered activated carbon in the softener for taste and odor removal. Others use activated carbon filters. If iron or manganese is present, aeration of the water before entering the softener will result in its removal.

Boiler Feedwater.—The boiler feedwater may be softened by the sodium zeolite process, hydrogen-ion exchange process, or hot lime-soda process. Care should be taken that the concentration of the boiler salines be kept low enough to avoid carry-over.

Water for Bottle Washers, Keg Washers, and Pasteurizers.—Water used for bottle washers, keg washers, and pasteurizers should be of zero hardness, the reasons being obvious. In pasteurizing, waters which are high in bicarbonate hardness form unsightly deposits on the outside of the bottles, necessitating polishing operations; softening of the water eliminates these deposits. Frequently, breweries use zeolite water softeners for softening the boiler feedwater and also the water used for bottle washers, keg washers, and pasteurizers.

Cooling Water.—The cooling water, if not re-used, frequently is not treated. If re-used or if scale formation is serious, treatment of the cooling water may be ef-

³³ E. Nordell, *The Brewer and Distributor*, I, 3 (August 15, 1933).

³⁴ E. Nordell, *Brewers Digest* (December, 1940).

⁴⁰ F. J. Lammers, *Modern Brewer* (July, 1939).

⁴¹ H. Luers and G. Fries, *Wochschr. Brau.*, 16, 121 (1939).

fected by: (1) the zeolite process or the sulfuric acid process (if the water is re-used) or (2) by the sulfuric acid process (if the water is used once and then run to waste).

4. Canning

In addition to meeting the general requirements previously outlined, water used for canning⁴² peas, beans, and lentils should be of zero hardness because the legumes abstract hardness from the water in which they are processed. This has a very marked toughening effect on the product. Zeolite water softeners are therefore widely employed in canneries in which legumes constitute at least part of the pack. In such canneries, the zeolite-softened water is also employed in canning other products, although the deleterious effects of hard water are probably absent in the case of acid products and not particularly marked with many other products.

The water used in cookers should be free of bicarbonate hardness or unsightly calcium carbonate deposits form on the outside of the tin or glass containers, thus often necessitating polishing operations. The sodium alkalinity of the water in the cookers should also be low, as high sodium alkalinitiess attack tin containers, giving them a spangled appearance. With the advent of the hydrogen-ion exchangers, it is now possible, by mixing the effluents of a hydrogen-ion exchanger and a sodium zeolite water softener, to produce a water free from hardness and of any required degree of alkalinity. While this process has not as yet come into general use in canneries, it undoubtedly will, in the future, be widely used where waters of zero hardness and low alkalinity are required.

The water used for general cleansing purposes should be of zero hardness and the water used for boiler feed should be softened. Many canneries employ zeolite-softened water for all purposes because it makes for simplicity of operation. In others, zeolite-softened water is used for processing and cleansing and a separate water-softening system, such as the hot lime-soda water softener or hydrogen-ion exchanger, is used for the boiler feedwater.

5. Citrus Fruit Packing

When hard water is used for washing citrus fruits, the dust and dirt tend to cling to the fruits and give them a dingy and unattractive appearance. Softening the water used in washing the fruit has been found to loosen and remove the dirt, thus furnishing a clean and attractive product. Sodium zeolite water softeners are the types used.

6. Confectionery Making

It has been pointed out by Jordan⁴³ in his book, *Confectionery Problems*, that differing compositions of water are responsible for the failures encountered in trying

⁴² K. G. Weckel, *Food Industries*, 14, 47 (1942).

⁴³ S. Jordan, *Confectionery Problems*. Nat'l Confect. Assoc., Chicago, 1930.

to use the same manufacturing formulas in various localities. He suggests that a distilled water with just a trace of alkalinity in it would obviate these manufacturing difficulties. While little, so far, has been done on this, it would appear that demineralization would be of advantage in furnishing a uniform quality of water in all localities because it would contain no more than a trace of salts and the ρH could be easily adjusted to any desired value.

For the boilers and general cleansing purposes, water softeners are employed in this industry, both of the zeolite and hot lime-soda types. Development in the treatment of process water in the future will probably be along the lines suggested.

7. Dairying

In addition to the general requirements, the water used in dairies^{44, 45} for can washing, bottle washing, and general cleansing purposes should be of zero hardness. Hard waters are not satisfactory for cleansing purposes and, with alkaline solutions, form clogging deposits in nozzles, circulating systems, and pumps on the washers, and unsightly deposits on the bottles. Bicarbonate hardness forms clogging scale deposits in water heaters, hot water piping, pasteurizers, and water-cooled systems. In the boiler feedwater, hardness in any form should be avoided.

The water-softening process most widely used in the dairies is the sodium zeolite process. This water is generally used for can washers, bottle washers, pasteurizers, water heaters, and boilers. Where the dairy manufactures ice, the water used for this purpose is generally not especially treated, as usually little regard is paid to the appearance of the ice. If clear ice is desired and the water to be used is high in bicarbonate hardness, the cold lime water softening process or the hydrogen-ion exchange process should be used.

In the manufacture of butter and cheese, special care should be exercised to keep tastes, odors, and organic growths of any nature out of the water supply.

8. Distilling

The water used in the distillery may be divided into five classifications as follows: water for mash making; cooling water for mash coolers; cooling water for condensers; boiler feedwater; and water for deproofing.

Mashing.—The water used should meet the general requirements. Some distilleries use hard limestone waters for mashing. Others use natural waters which are low in hardness.

Mash Coolers.—The water used, unless re-used or unless scale formation is very heavy, is generally not specially treated. If the water is re-used for cooling purposes, the sodium zeolite process, the cold lime plus zeolite process, or the sulfuric acid treatment may be employed. If scale formation is very heavy and the water is not re-used, the sulfuric acid treatment may be employed.

⁴⁴ D. C. Jordan, *Creamery J.* (October, 1939).

⁴⁵ U. A. Hammett, *Ice and Refrig.*, 98, 116 (1940).

Condenser Cooling Water.—Scale formation in the condensers cuts down production. Cooling water for the beer stills and column stills should therefore be so treated as to stop scale formation. This cooling water is never re-used for cooling purposes. In some distilleries, where the amount of cooling water used for these purposes is approximately that required for the boilers, the sodium zeolite water softening process is employed. In such cases the softened water, after being used for cooling, is then used as boiler feedwater. In distilleries in which water is used for cooling and then run to waste, the sulfuric acid treatment may be employed.

Boiler Feedwater.—Boiler feedwater is softened by the sodium zeolite process, the hydrogen-ion exchange process, or the hot lime-soda process.

Deproofing.—Distilled water is generally used because some of the mineral salts present in tap water precipitate in alcoholic liquors. There is a definite trend, however, toward the use of demineralized water for this purpose, for demineralized water compares very favorably with distilled water in quality and costs very much less to produce.

9. Gelatin Manufacture

Requirements for gelatin^{46, 47} will be different depending on whether it is to be used for edible, photographic, or other purposes. Since the viscosity and jelly strength of gelatin solutions are functions of its ash content, the ash content should be kept low. Demineralizing will be, in most cases, a solution for the preparation of water which is practically free of electrolytes; the trend in the future will probably be in this direction. The zeolite process, the hydrogen-ion exchange process, and the hot lime-soda process are employed for the softening of the boiler feedwater.

10. Fruit Acids and Pectin Manufacture

In the manufacture of fruit acids and pectin^{48, 48a, 49} it is essential that the ash content be eliminated or reduced to a minimum. Calcium pectate or calcium citrate or the calcium salts of other fruit acids may be converted to their respective acids by cation exchangers operating on the hydrogen cycle.

11. Meat Packing

Zeolite water softeners are widely employed in packing houses in softening water for the boilers, for cooling purposes, and for general cleansing purposes. It is claimed that better color is obtained with pickled meats when softened water is employed in washing them. Other types of water-treating equipment employed by the packing houses are filters, iron-removal equipment, organic cation exchangers, and hot lime-soda water softeners.

⁴⁶ E. E. Jelley, U. S. Pat. 2,273,557, February 17, 1942.

⁴⁷ E. L. Holmes, U. S. Pat. 2,240,116, April 29, 1941.

⁴⁸ G. M. Cole, U. S. Pat. 2,253,061, August 19, 1941.

^{48a} P. B. Myers and A. H. Rouse, U. S. Pat. 2,323,483, July 6, 1943.

⁴⁹ W. E. Baier and C. W. Wilson, *Ind. Eng. Chem.*, **33**, 287 (1941).

12. Starch Manufacture

Hard water increases the ash content of starch. Iron is objectionable on account of the discolorations produced. It is claimed that high magnesium contents in the water are troublesome and lead to formation of cloudiness in the manufacture of corn syrup. Zeolite water softeners, filters, and iron-removal plants are employed. Hot lime-soda water softeners are also employed for treating the boiler feedwater.

13. Sugar Refining

It is well known that electrolytes cause inversion of sugar. In some refineries using surface waters, therefore, a constant watch is kept to avoid contamination with sea water because it decreases the yield of sucrose. Experimental work has been done on demineralization of the process water and extraction of mineral substances from the cane and sugar beet juices and practical applications will probably be made in the future.

Filters are widely employed in treating process water in sugar refining.⁵⁰⁻⁵² Zeolite water softeners are also widely used. Some refineries operate their boilers on the condensate from the evaporators. Others do not use condensates for boiler feedwater on account of the danger of having sugar enter the boilers. In such refineries, the boiler feedwater is separately treated, either by the zeolite or hot lime-soda process.

In the manufacture of maple syrup, cation exchangers have been used to remove such toxic metallic impurities as lead.

14. Vitamin Production and Assaying

The 20th century has witnessed a rapid development in the field of vitamins.⁵³⁻⁵⁶ These compounds have certain functional groups which can be utilized in ion-exchange reactions.

Cation exchange materials such as Folin Decalso have already proved their value in the concentration and assay of vitamin B₁.

The development of modern ion-exchange materials opens a new field in the manufacture of this group of substances, which are so essential to the human life.

⁵⁰ F. N. Rawlings and R. W. Shafor, *Sugar*, 37, 26 (1942).

⁵¹ C. O. Willits and C. J. Tressler, *Food Research*, 4, 461 (1939).

⁵² F. W. Weitz, *Sugar*, 38, 26 (1943).

⁵³ H. R. Rosenberg, *The Chemistry and Physiology of Vitamins*. Interscience, New York, 1942.

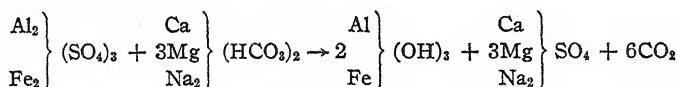
⁵⁴ L. R. Cerecedo and D. J. Hennessy, *J. Am. Chem. Soc.*, 59, 1617 (1937).

⁵⁵ L. R. Cerecedo and F. J. Kaszuba, *J. Am. Chem. Soc.*, 59, 1619 (1937).

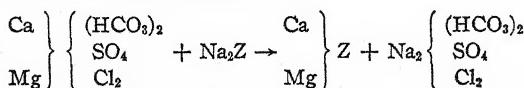
⁵⁶ L. R. Cerecedo and J. J. Thornton, *J. Am. Chem. Soc.*, 59, 1621 (1937).

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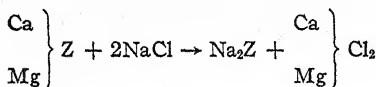
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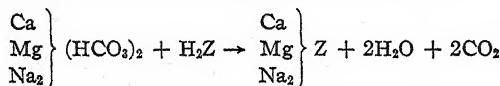
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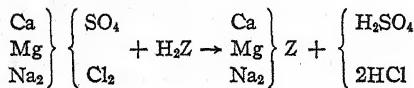
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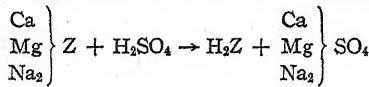
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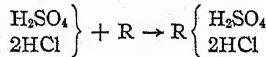
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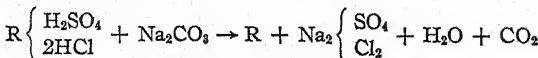
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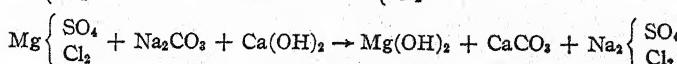
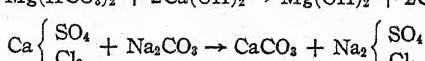
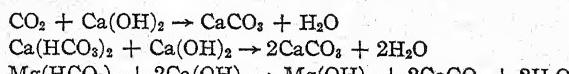
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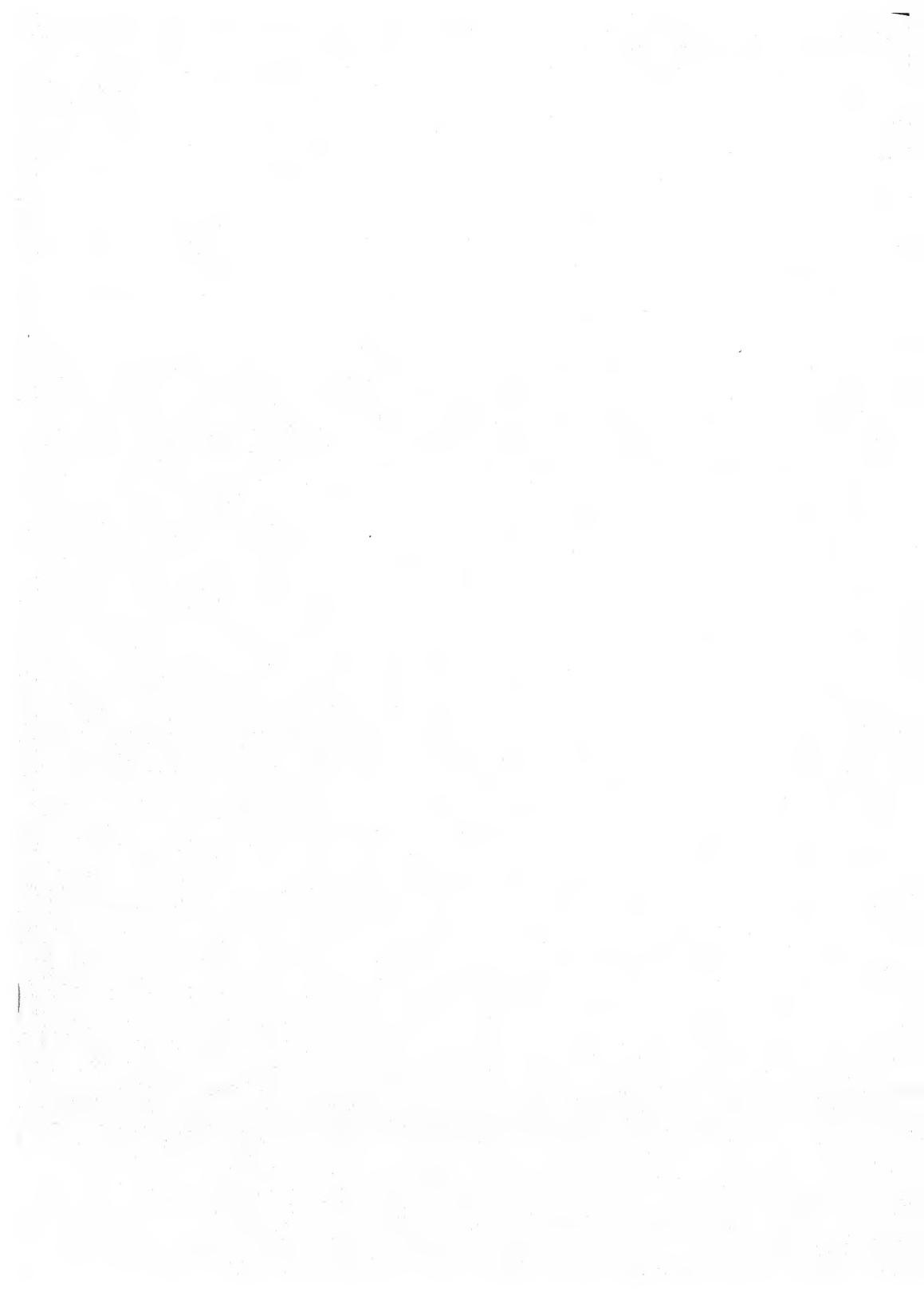


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